Design Example Report

Title	***14 W Non-Dimmable, High Efficiency (>86%), Power Factor Corrected Isolated Flyback LED Driver Using LYTSwitch™-5 LYT5226D***
Specification	90 VAC – 265 VAC Input; 20 V_{MIN} – 40 V_{MAX}, 350 mA_{TYP} Output
Application	Down Light
Author	Applications Engineering Department
Document Number	DER-528
Date	March 09, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Wide output LED voltage range (20 V_{MIN} - 40 V_{MAX}) with accurate current regulation, ±5%
- Highly energy efficient, >86% at 115 V / 230 V
- Low cost and low component count for compact PCB solution
- Integrated protection features
  - No-load and output short-circuit protection
  - Input and output OVP
  - Thermal foldback protection
  - Over temperature protection
  - No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 1 kV differential surge
- Meets EN55015 conducted EMI with LED heat sink grounded

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Important Note: Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This engineering report describes a non-dimmable, isolated flyback LED driver designed to drive a 20 V to 40 V LED voltage string at 350 mA from an input voltage range of 90 VAC to 265 VAC. The LED driver utilizes the LYT5226D from the LYTSwitch-5 family of devices.

LYTSwitch-5 is a non-dimmable LED driver IC with single stage PFC function and accurate LED current control. LYTSwitch-5 incorporates a high-voltage power MOSFET and discontinuous mode, variable frequency, variable on-time controller. The controller also provides fast (cycle-by-cycle) current limit, input and output OVP, plus advanced thermal management circuitry.

DER-528 provides a 350 mA nominal constant current output within 20 V_{MIN} – 40 V_{MAX} output LED voltage ranges. The key design goals were high efficiency and constant current regulation throughout a wide input and output voltage range.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet and performance data.

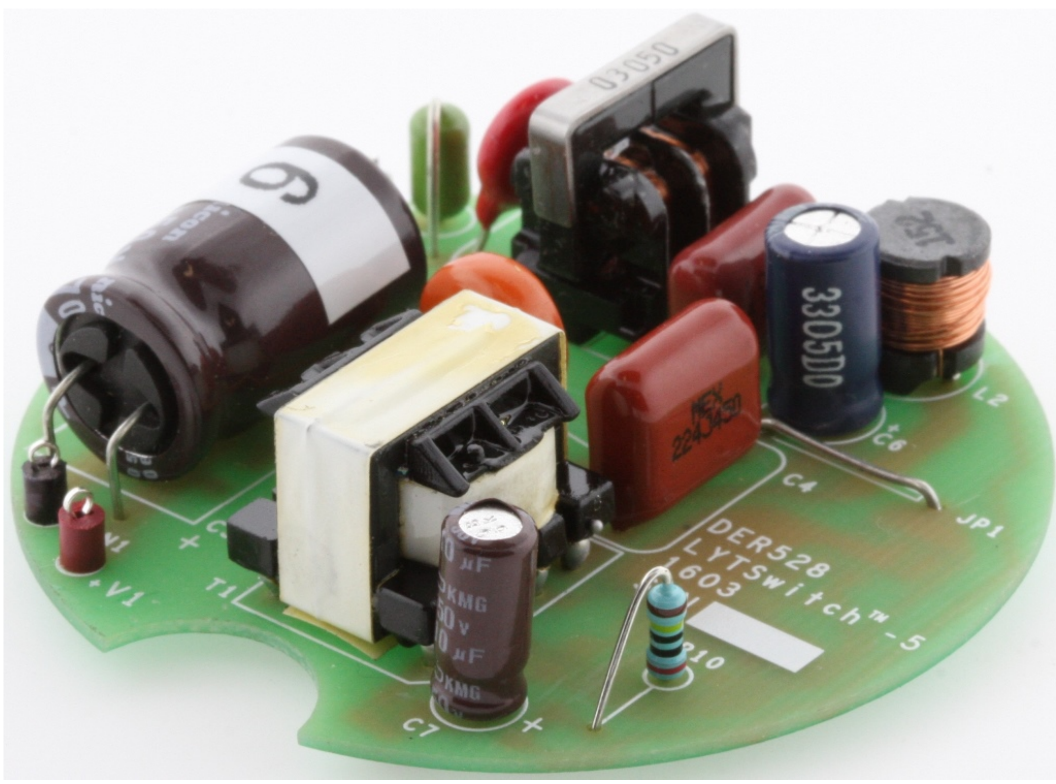

Figure 1 – Populated Circuit Board.

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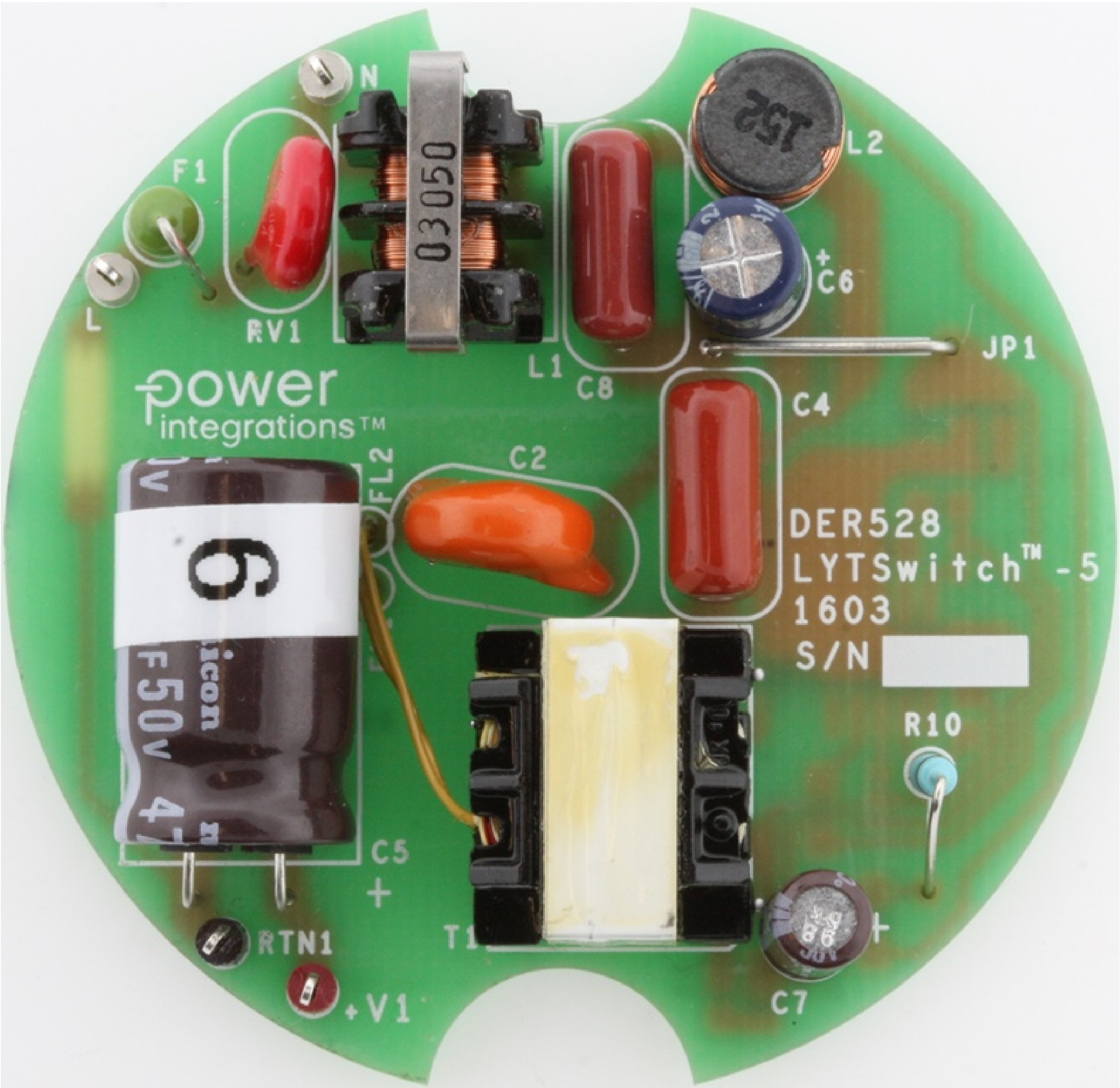

Figure 2 – Populated Circuit Board, Top View.

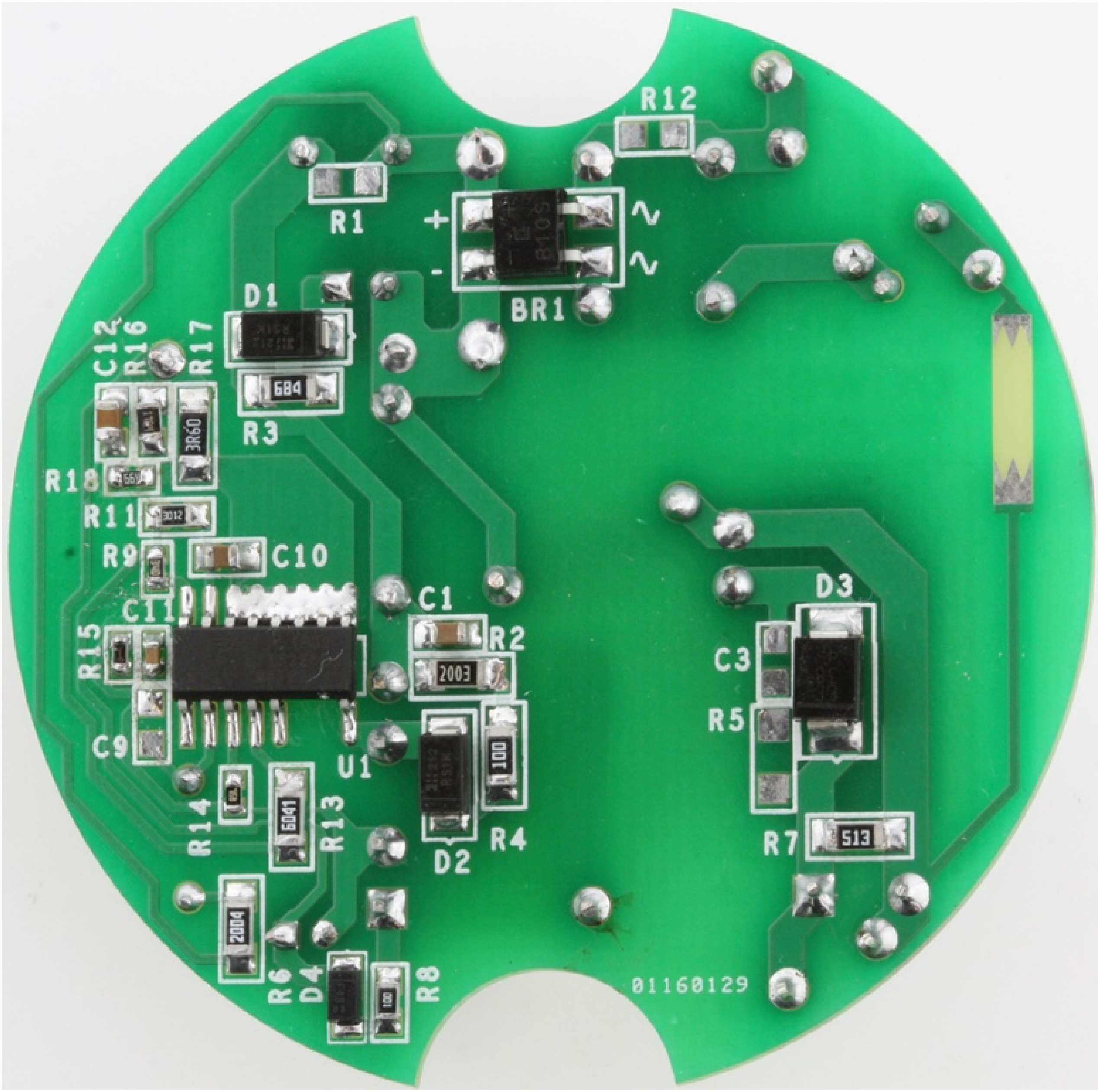

Figure 3 – Populated Circuit Board, Bottom View.

Note: The following component locations were unstuffed (not populated): R12, R1, R5, C3, and C9

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2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115/230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60/50		Hz	
Output						
Output Voltage	V_{OUT}	20	30	40	V	
Output Current	I_{OUT}		350		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		14		W	
Efficiency						
Full Load	η		86		%	115 V / 60 Hz and 230 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI			CISPR 15B / EN55015B			
Safety			Isolated			
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 230 VAC / 50 Hz and 115 VAC / 60 Hz.
Ambient Temperature	T_{AMB}			85	^{o}C	Free Convection, Sea Level.

3 Schematic

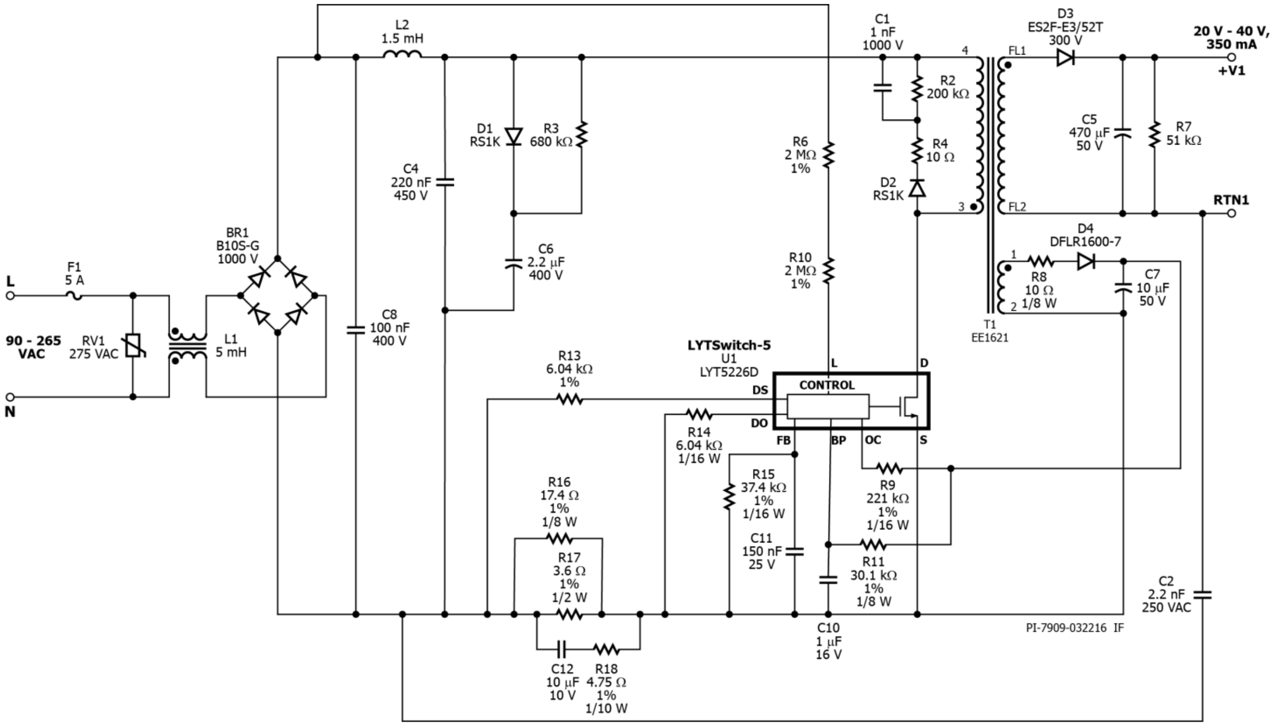

Figure 4 – Schematic.

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4 Circuit Description

The LYTSwitch-5 device (U1-LYT5226D) combines a high-voltage power MOSFET and a power supply controller in a single SO16 package. IC U1 is configured to drive a 14 W isolated flyback LED driver throughout a wide input (90 V – 265 V) and output voltage (20 V_{MIN} – 40 V_{MAX}) range.

4.1 Input Stage

Fuse F1 provides safety protection from component failures. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage (265 VAC).

The AC input is full wave rectified by BR1 to achieve good power factor and low THD.

4.2 EMI Filters

The differential choke L2, together with the input filter capacitor C8 and C4 work as an EMI π filter. The π filter together with common mode choke L1, Y-capacitor C2 and the LYTSwitch-5 frequency jittering feature ensure compliance with the EN55015 Class B emission limit.

4.3 LYTSwitch-5 Primary Control Circuit

The topology is an isolated flyback. The primary winding finish terminal (no dot end) of the transformer (T1) is connected to the DC bus and the start (dotted end) terminal to the DRAIN (D) pin of the LYTSwitch-5 IC. During the on-time of the power MOSFET, current ramps through the primary winding, storing energy which is then delivered to the output load via output diode D3 during the power MOSFET off-time.

During the power MOSFET off time RCD snubber D2, R2, R4 and C1 clamp the leakage voltage spike to a safe level. Output capacitor C5 provides output voltage filtering minimizing the output LED ripple current with R7 acting as preload.

Diode D4 and C7 deliver the primary bias supply for U1 from transformer auxiliary winding. For a wide output LED voltage application, the bias voltage is set to 30 V at maximum LED output voltage. The use of an external bias supply (via R11) is recommended to give the lowest device dissipation and provide sufficient supply to U1 at low LED voltage. Resistor R8 is added to dampen the leakage ring from the bias winding that could mis-trigger the device output OVP function.

Capacitor C10 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the IC. During start-up, the bypass capacitor C10 is charged to ~5.25 V from IC internal high-voltage current source connected to the D pin.

To provide input line voltage information to U1, the input AC voltage is sensed directly after the bridge rectifier diode through sampling resistors R6 and R10. The device input OVP function is activated when line sense current exceeds the OVP threshold. With reference to the FEEDBACK (FB) pin threshold of 300 mV, R17 and R16 senses the output LED current through U1 drain current and is then fed into the U1 DRIVER CURRENT SENSE (DS) pin via R13 to maintain the output constant current regulation. When the detected signal is above or below the preset average V_{FB} threshold voltage, the controller will adjust the frequency and/or on-time to maintain regulation. Capacitor C12 and R18 provide voltage filtering and input line compensation to the sense resistor for a more optimized output current regulation throughout the input range. The IC U1 OUTPUT COMPENSATION (OC) pin senses the output voltage through the bias winding via R9 (R_{OC}) for the output OVP function at open load and for an optimized LED current regulation throughout the output voltage range. When the OC pin current exceeds the OV threshold, output OVP is activated with the IC latching off. This will prevent the output voltage from rising further. An AC recycle is needed to reset this protection mode once triggered. For wide-output LED applications, the R_{OC} resistor (value) should be centered between I_{OUV} (output undervoltage) and I_{OOV} (output overvoltage).

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5 PCB Layout

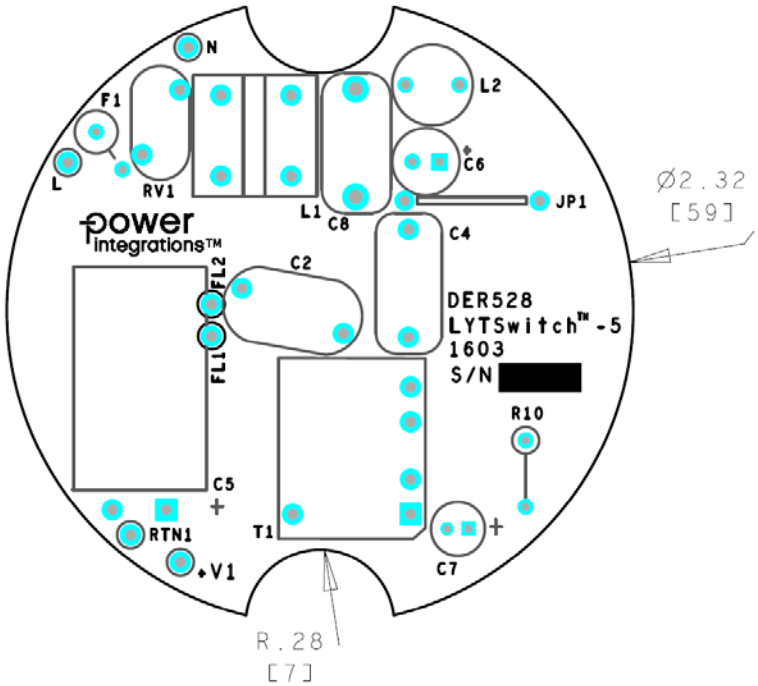

Figure 5 – Top Side.

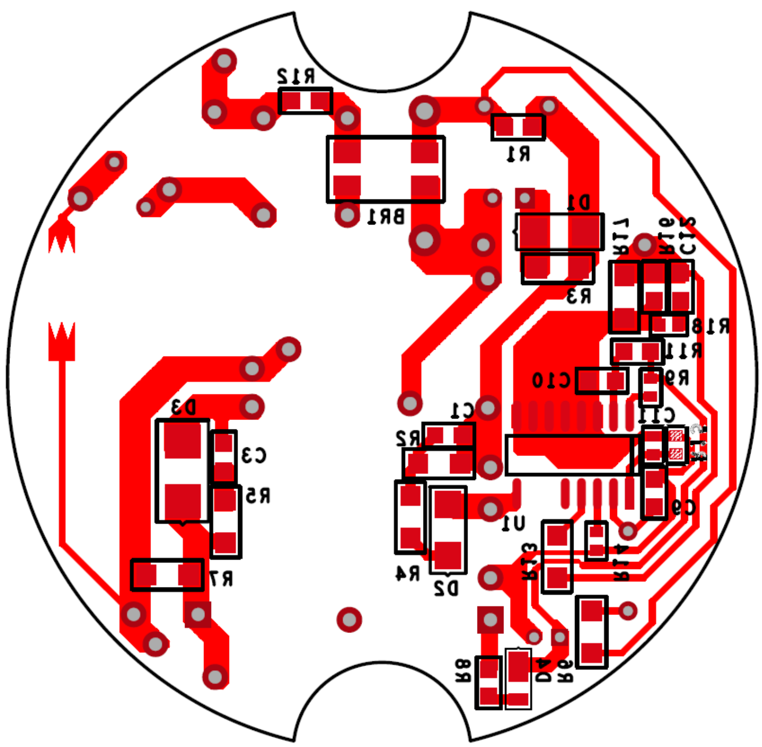

Figure 6 – Bottom Side.

Note: The following component locations were unstuffed (not populated): R12, R1, R5, C3, and C9.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	1 nF, 1000 V, Ceramic, X7R, 0805	C0805C102KDRACTU	Kemet
3	1	C2	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
4	1	C4	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
5	1	C5	470 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 20)	UPW1H471MHD	Nichicon
6	1	C6	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
7	1	C7	10 μF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG500ELL100ME11D	Nippon Chemi-Con
8	1	C8	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
9	1	C10	CAP, CER, 1 μF, 16V, X7R, 0805	GRM21BR71C105KA01K	Murata Electronics
10	1	C11	150 nF, 25 V, Ceramic, X7R, 0603	C1608X7R1E154K080AA	TDK
11	1	C12	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
12	1	D1	800 V, 1 A, Fast Recovery, 250 ns, SMA	RS1K-13-F	Diodes, Inc.
13	1	D2	800 V, 1 A, Fast Recovery, 250 ns, SMA	RS1K-13-F	Diodes, Inc.
14	1	D3	300 V, 2 A, Ultrafast Recovery, 50 ns, SMB Case	ES2F-E3/52T	Vishay
15	1	D4	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
16	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
17	1	JP1	Wire Jumper, Non-insulated, #22 AWG, 0.5 in	298	Alpha
18	1	L1	5 mH, 0.3 A, Common Mode Choke	SU9V-03050	Tokin
19	1	L2	1.5 mH, 0.23 A, Ferrite Core	CTCH895F-152K	CTParts
20	1	R2	RES, 200 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ204V	Panasonic
21	1	R3	RES, 680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
22	1	R4	RES, 10 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ100V	Panasonic
23	1	R6	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
24	1	R7	RES, 51 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ513V	Panasonic
25	1	R8	RES, 10 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
26	1	R9	RES, 221 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2213V	Panasonic
27	1	R10	RES, 2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole
28	1	R11	RES, 30.1 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
29	1	R13	RES, 6.04 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF6041V	Panasonic
30	1	R14	RES, 6.04 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6041V	Panasonic
31	1	R15	RES, 37.4 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3742V	Panasonic
32	1	R16	RES, 17.4 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF17R4V	Panasonic
33	1	R17	RES, SMD, 3.6 Ω, 1%, 200 ppm, 1/2 W, 1206, Automotive, AEC-Q200, Current Sense	ERJ-8BQF3R6V	Panasonic
34	1	R18	RES, SMD, 4.75 Ω, 1%, 1/10 W, ±200 ppm/°C, 0603	RC0603FR-074R75L	Yageo
35	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
36	1	T1	Bobbin, EE1621, Vertical, 8 pins, 4pri, 4sec	EE-1621	Shen Zhen Xin Yu Jia Tech
37	1	U1	LYTSwitch-5, SO-16B, High voltage	LYT5226D	Power Integrations

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7 Inductor Specification

7.1 Electrical Diagram

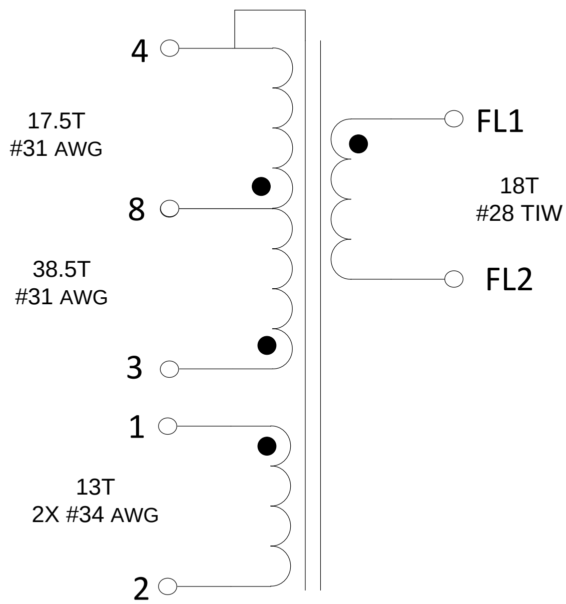

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 2, with all other windings open.	420 μH
Tolerance	Tolerance of primary inductance.	±5%

7.3 Material List

Item	Description
[1]	Core: EE1621.
[2]	Bobbin, EE1621, Horizontal, 10 pins, Part no. 25-01044-00.
[3]	Magnet Wire: #31 AWG.
[4]	Magnet Wire: #34 AWG.
[5]	Triple Insulated Wire: #28 AWG.
[6]	Polyester Tape: 5.5 mm.
[7]	Transformer Tape: 6 mm.
[8]	Non-insulated Wire: #30 AWG.

7.4 Inductor Build Diagram

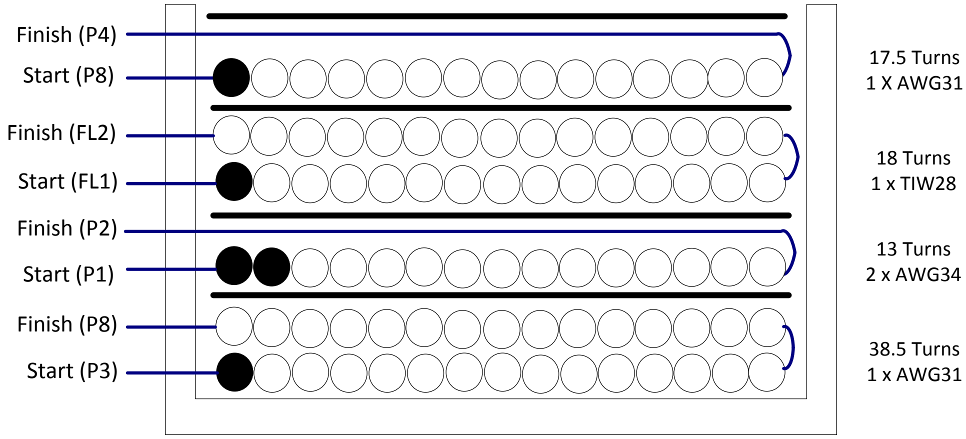

Figure 8 – Transformer Build Diagram.

7.5 Inductor Construction

Bobbin Modification	Cut the bobbin extension as shown on figure below.
Winding Directions	Bobbin placed on winder jig such that terminal pin 1-4 is in the left side. The winding direction is clockwise.
Winding 1	Use wire item [3], start at pin 3 and wind 38.5 turns in 2 layers, then finish the winding on pin 8.
Insulation	Add 1 layer of tape, item [6], for insulation.
Winding 2	Use wire item [4] in bifilar, start at pin 1 and wind 13 turns evenly from left to right, then finish the winding on pin 2.
Insulation	Add 1 layer of tape, item [6], for insulation.
Winding 3	Use wire item [5], allot 25 mm length for fly lead wire no.1 (mark as FL1) then wind 18 turns from left to right, finished the winding with 25 mm length fly lead wire no. 2 (mark as FL2).
Insulation	Add 1 layer of tape, item [7], for insulation.
Winding 4	Use wire item [3], start at pin 8 and wind 17.5 turns in 1 layer, then finish the winding on pin 4.
Insulation	Add 1 layer of tape, item [6], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 420 μH with ±5% inductance tolerance.
Assemble Core	Assemble the 2 cores on the bobbin with the gapped core place on top side of the bobbin and the un-gapped core at the bottom side. Wrap the cores with tin wire and terminate it to pin 4. Wrap the 2 cores with 2 layer of tape, item (6).
Pins	Pull out terminal pin no. 7
Finish	Dip the transformer assembly in varnish.

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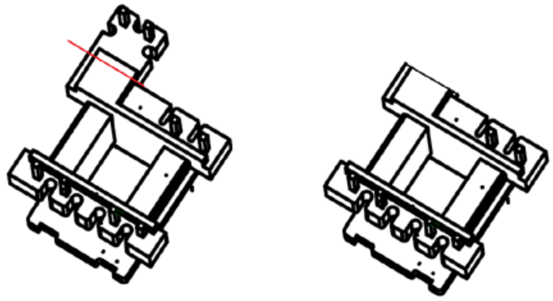
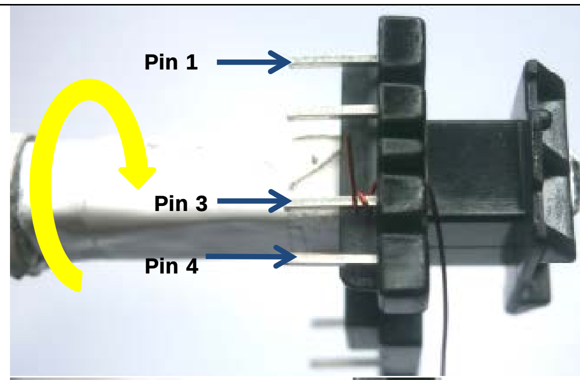
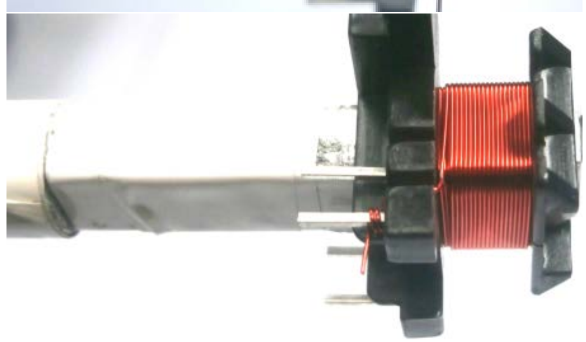
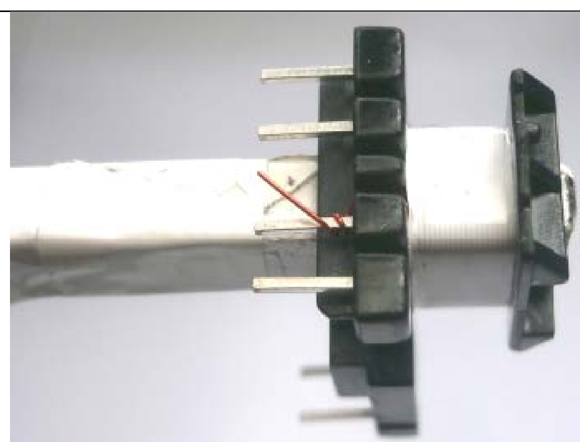
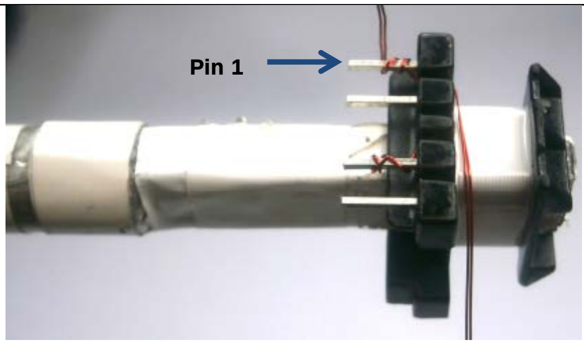
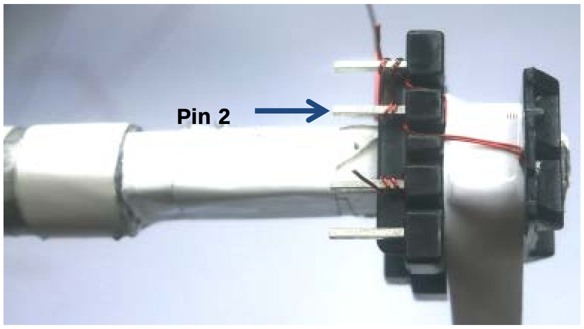
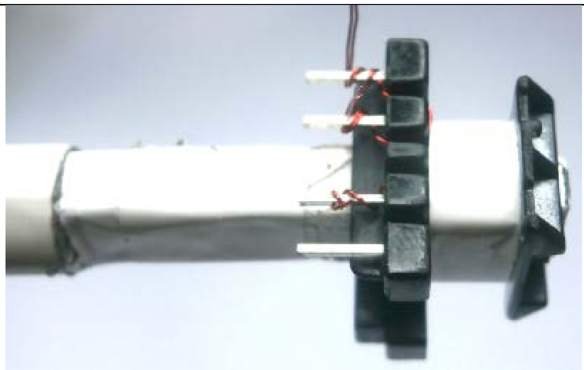
7.6 Winding Illustrations

Bobbin Modification Cut the bobbin extension as shown in the figure.	
Winding Directions Bobbin placed on winder jig such that terminal pin 1-4 is in the left side. The winding direction is clockwise. **Winding 1** Use wire item [3], start at pin 3 and wind 38.5 turns in 2 layers, then finish the winding on pin 8.	 
Insulation Add 1 layer of tape, item [6], for insulation.	

Winding 2 Use wire item [4] in bifilar, start at pin 1 and wind 13 turns evenly from left to right, then finish the winding on pin 2.	 
Insulation Add 1 layer of tape, item [6], for insulation.	

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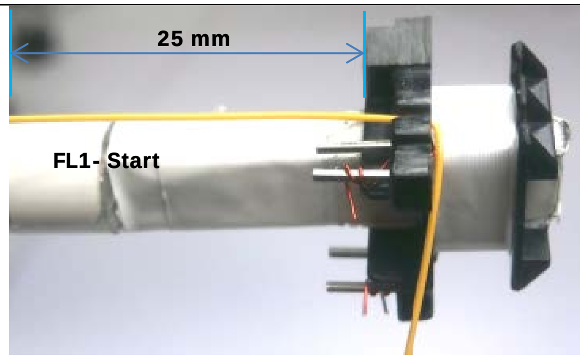
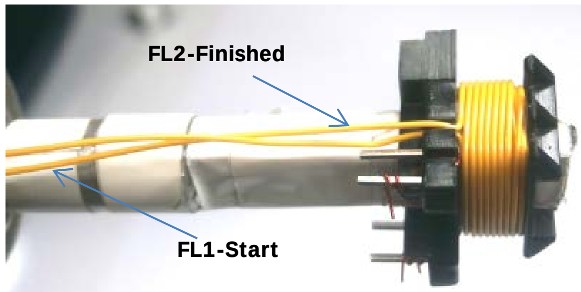
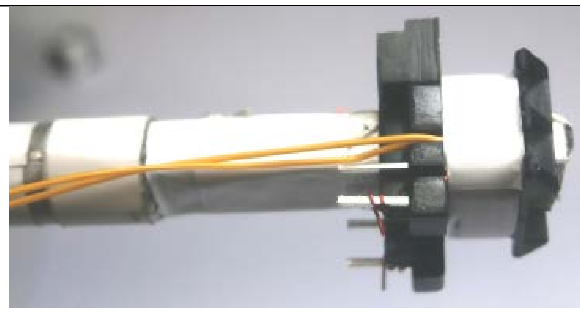
<table>
<tr><td>Winding 3

Use wire item [5], allot 25 mm length for fly lead wire no.1 (mark as FL1) then wind 18 turns from left to right, finish the winding with 25 mm Length fly lead wire no. 2 (mark as FL2).</td><td>


</td></tr>
<tr><td>Insulation

Add 1 layer of tape, item [7], for insulation.</td><td></td></tr>
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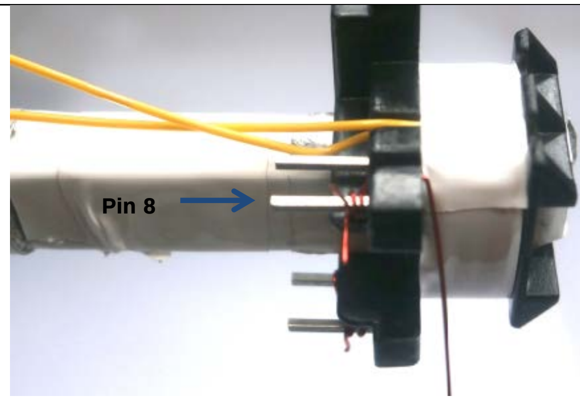
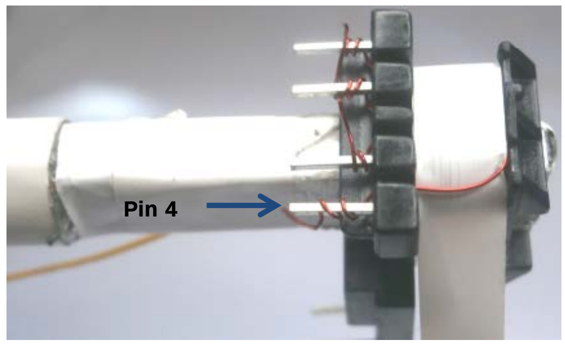
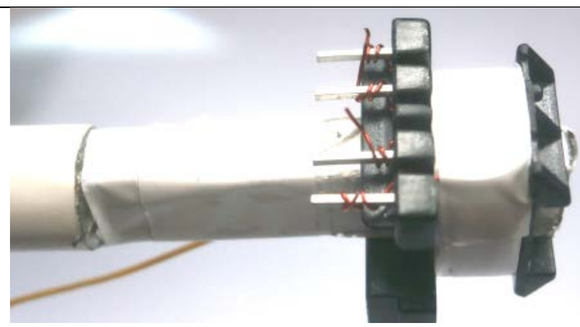
Winding 4 Use wire item [3], start at pin 8 and wind 17.5 turns in 1 layer, then finish the winding on pin 4.	 
Insulation Add 1 layer of tape, item [6], for insulation.	

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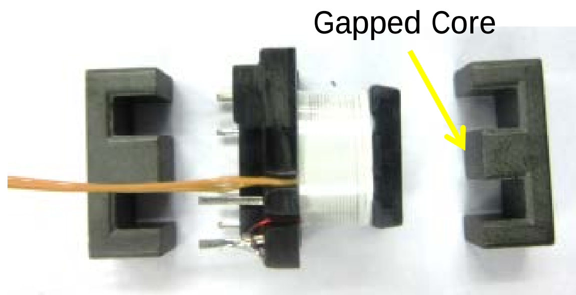
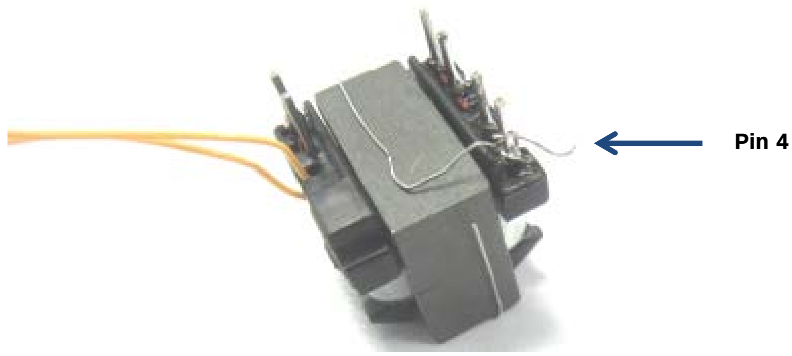
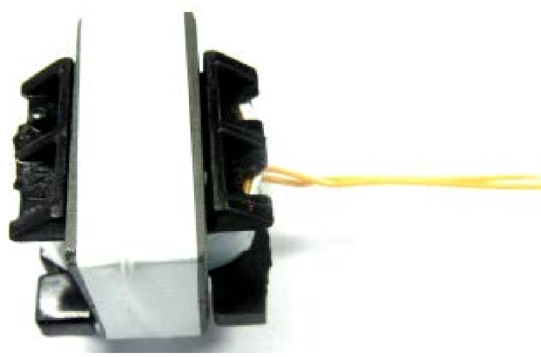
Assemble Core Assemble the 2 cores on the bobbin with the gapped core placed on top side of the bobbin and the un-gapped core at the bottom side. Wrap the cores with tin wire (item 8) and terminate it to pin 4. Wrap the 2 cores with 2 layers of tape, item (7).	 
Finish Dip the transformer assembly in 2:1 thinner and varnish solution.	

8 Inductor Design Spreadsheet

ACDC LYTSwitch5 IsolatedFlyback 011916; Rev.1.0; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNITS	LYTSwitch-5 Isolated Flyback Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	90.0		90.0	Volts RMS	Minimum AC line voltage.
VACNOM			177.5	Volts RMS	Nominal AC line voltage.
VACMAX	265.0		265.0	Volts RMS	Maximum AC line voltage.
FL			50	Hertz	AC line frequency.
VO_MIN			36.0	Volts DC	Guaranteed minimum VO that maintains output regulation.
VO	40.0		40.0	Volts DC	Worst case normal operating output voltage.
VO_OVP_MIN			52.7	Volts DC	Minimum Voltage at which output voltage protection may be activated.
IO	350.0		350.0	m-Amperes	Average output current specification.
EFFICIENCY	0.87		0.87	Dimensionless	Total power supply efficiency.
Z			0.50	Dimensionless	Loss allocation factor.
PO			14.00	Watts	Output power.
LYTSwitch-5 DESIGN VARIABLES					
BREAKDOWN VOLTAGE	725		725	Volts DC	Choose between 650V and 725V.
GENERIC DEVICE	LYT52X6D		LYT52X6D		Chosen LYTSwitch-5 generic device.
ACTUAL DEVICE			LYT5226D		Chosen LYTSwitch-5 device code.
ILIMITMIN			1.767	Amperes	Minimum device current limit.
ILIMITTYP			1.900	Amperes	Typical Current Limit.
ILIMITMAX			2.033	Amperes	Maximum Current Limit.
IP_MOSFET			1.319	Amperes	Worst case peak drain current of the MOSFET.
TON_MIN			1.327	u-seconds	Worst case minimum on-time of the MOSFET.
TON_MAX			3.887	u-seconds	Worst case maximum on-time of the MOSFET.
IAVG_MOSFET			0.167	Amperes	Worst case average drain current of the MOSFET.
IRMS_MOSFET			0.320	Amperes	Worst case maximum RMS current of the MOSFET.
KDP			1.123	Dimensionless	Ratio between off-time of the MOSFET and on-time of the secondary diode.
VDRAIN			529.8	Volts DC	Estimated worst case drain voltage of the MOSFET.
DEVICE PROGRAMMING PARAMETERS					
RDO			6	k-ohms	DO pin resistor.
RDS			6	k-ohms	Current sense programming resistor connected to the DS pin for the isolated flyback converter.
ENTER TRANSFORMER CONSTRUCTION VARIABLES					
CORE TYPE	EE1621		EE1621		Core type.
AE	33.77		33.77	mm^2	Core effective cross sectional area.
LE	29.00		29.00	mm	Core effective path length.
AL	2600		2600	nH/T^2	Ungapped core effective inductance.
VE	980		980	mm^3	Core volume.
AW	15.00		15.00	mm^2	Window area of the bobbin.
BW	5.00		5.00	mm	Bobbin physical winding width.
MARGIN			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
TRANSFORMER DESIGN PARAMETERS					
Primary winding parameters					
LP	420		420	u-Henrys	Typical value of the primary inductance.
LP_TOL	5		5	%	Tolerance of the primary inductance.
LP_MIN			399	u-Henrys	Minimum value of the primary inductance.
LP_MAX			441	u-Henrys	Maximum value of the primary inductance.
NP			56	Turns	Number of primary turns.
ALG			133.93	nH/T^2	Gapped core effective inductance.
BM			3075	Gauss	Maximum flux density.
BP		Warning	4741	Gauss	The peak flux density is higher than 4200 Gauss.

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					Increase the number of primary winding turns to avoid core saturation.
BAC			1538	Gauss	Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak).
LG			0.3	mm	Core gap length.
LAYERS_PRIMARY_DESIRED			4	Dimensionless	Desired number of primary layers.
AWG_PRIMARY	31		31	AWG	Primary wire gauge.
OD_PRIMARY_INSULATED			0.272	mm	Outer diameter of the primary winding wire with insulation.
OD_PRIMARY_BARE			0.227	mm	Outer diameter of the primary winding wire without insulation.
IRMS_PRIMARY			0.320	Amperes	Maximum RMS current flowing through the primary winding.
CMA_PRIMARY			249	mils^2/Amperes	Primary winding CMA.
J_PRIMARY			7.92	Amperes/mm^2	Primary winding current density.
Secondary winding parameters					
VOR	125		125	Volts DC	Output voltage reflected to the primary winding when the MOSFET is off.
NS	18		18	Dimensionless	Number of secondary turns.
AWG_SECONDARY			27	Dimensionless	Secondary wire gauge.
OD_SECONDARY_INSULATED			0.418	mm	Outer diameter of the secondary winding wire with insulation.
OD_SECONDARY_BARE			0.361	mm	Outer diameter of the secondary winding wire without insulation.
IRMS_SECONDARY			0.979	Amperes	Maximum RMS current flowing through the secondary winding.
CMA_SECONDARY			206	mils^2/Amperes	Secondary winding CMA.
J_SECONDARY			9.59	Amperes/mm^2	Secondary winding current density.
Bias winding parameters					
VD_BIAS			0.70	Volts DC	Bias winding diode forward drop voltage.
BIAS TURNS			13	Turns	Number of bias winding turns.
VBIAS	28.0		28.0	Volts DC	Bias Voltage. Check performance at minimum VO and VACMAX.
PIVBS			132.4	Volts DC	Output Rectifier Maximum Peak Inverse Voltage (calculated at VACMAX)
CBIAS			22.0	u-Farads	Bias winding rectification capacitor.
RBP			25.00	k-Ohms	Bias supply resistor assuming 1mA current necessary to supply the BP pin.
CBP			2.2	u-Farads	Minimum BP pin capacitance.
SECONDARY DIODE PARAMETERS					
VF_DIODE			0.7	Volts DC	Output diode forward voltage drop.
IRMS_DIODE			0.979	Amperes	Diode RMS current at LP_MIN, VACMIN and PO_MAX.
IP_DIODE			4.103	Amperes	Diode peak current at LP_MIN ,VACMAX and PO_MAX.
PIV_DIODE			190.4	Volts DC	Peak Inverse Voltage at VO_MAX on output diode.
FEEDBACK AND PROTECTION PARAMETERS WITH FINE TUNING					
RL	4.00		4.00	M-Ohms	Standard (E96 / 1%) L pin resistor.
OVP_LINE			339.4	Volts RMS	Line overvoltage based on the actual L pin resistor used.
RDC_THEORETICAL			2.40	Ohms	Theoretical DS pin sense resistor.
RDC			2.43	Ohms	Standard (E96 / 1%) DS pin sense resistor.
CDC			10.0	u-Farads	Standard capacitor connected in parallel with the DS pin sense resistor.
VBIAS_MEASURED	30.0		30.0	Volts DC	Actual bias voltage (across the bias capacitor) measured on the bench.
VO_MEASURED			40.0	Volts DC	Actual load voltage measured on the bench.
ROC			280.0	k-Ohms	Standard (E96 / 1%) OC pin resistor.
IO_ACTUAL			350.0	m-Amperes	Actual output current seen on the bench.
RFB_THEORETICAL			39.5	k-Ohms	Calculated value of RFB, using standard values for RDS, ROVP, and RL

RFB			39.2	k-Ohms	Standard (E96 / 1%) F pin resistor.
CFB			150.0	n-Farads	Standard capacitor connected to the F pin.

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9 Performance Data

All measurements were performed at room temperature using LED load string. 1 minute soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

9.1 Efficiency

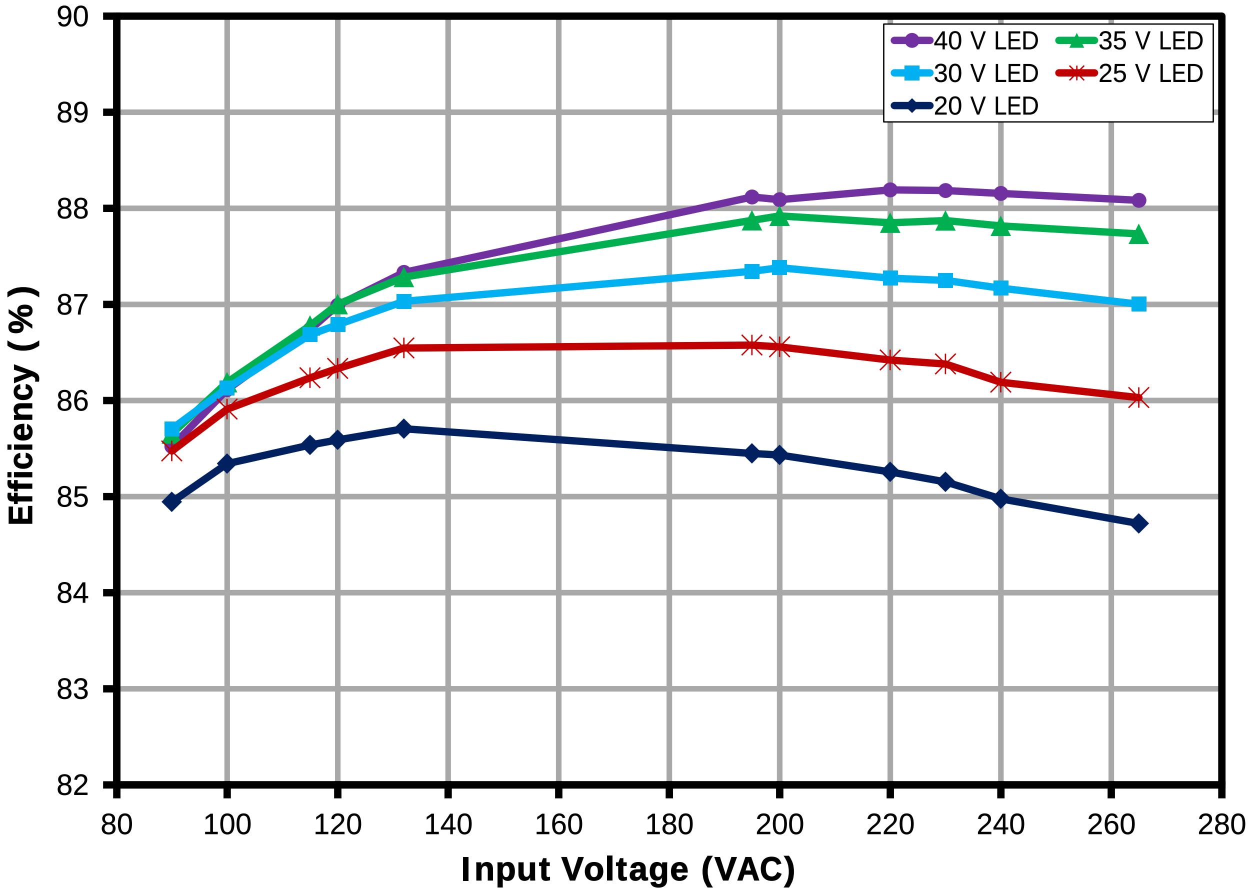

Figure 9 – Efficiency vs. Line and LED Load.

9.2 Line Regulation

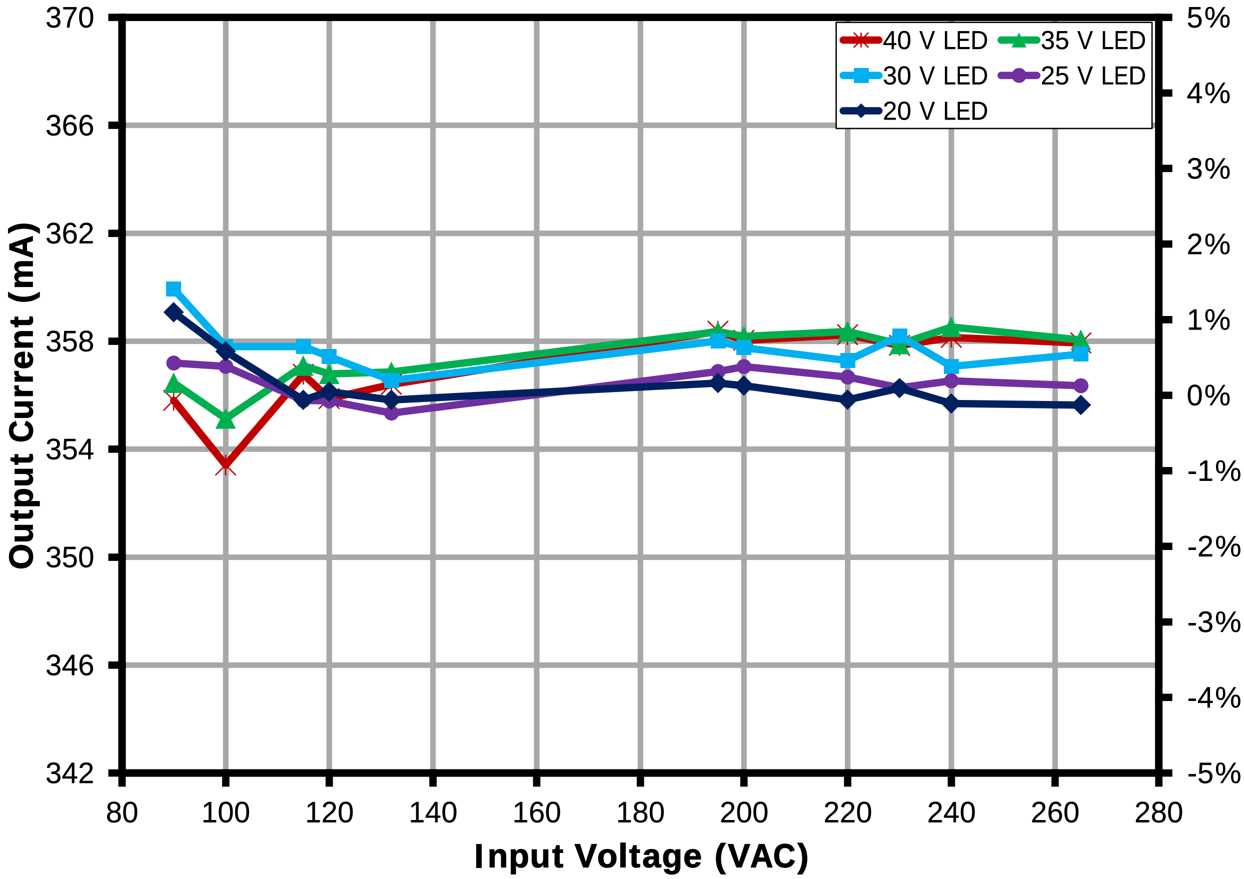

Figure 10 – Regulation vs. Line and LED Load.

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9.3 Power Factor

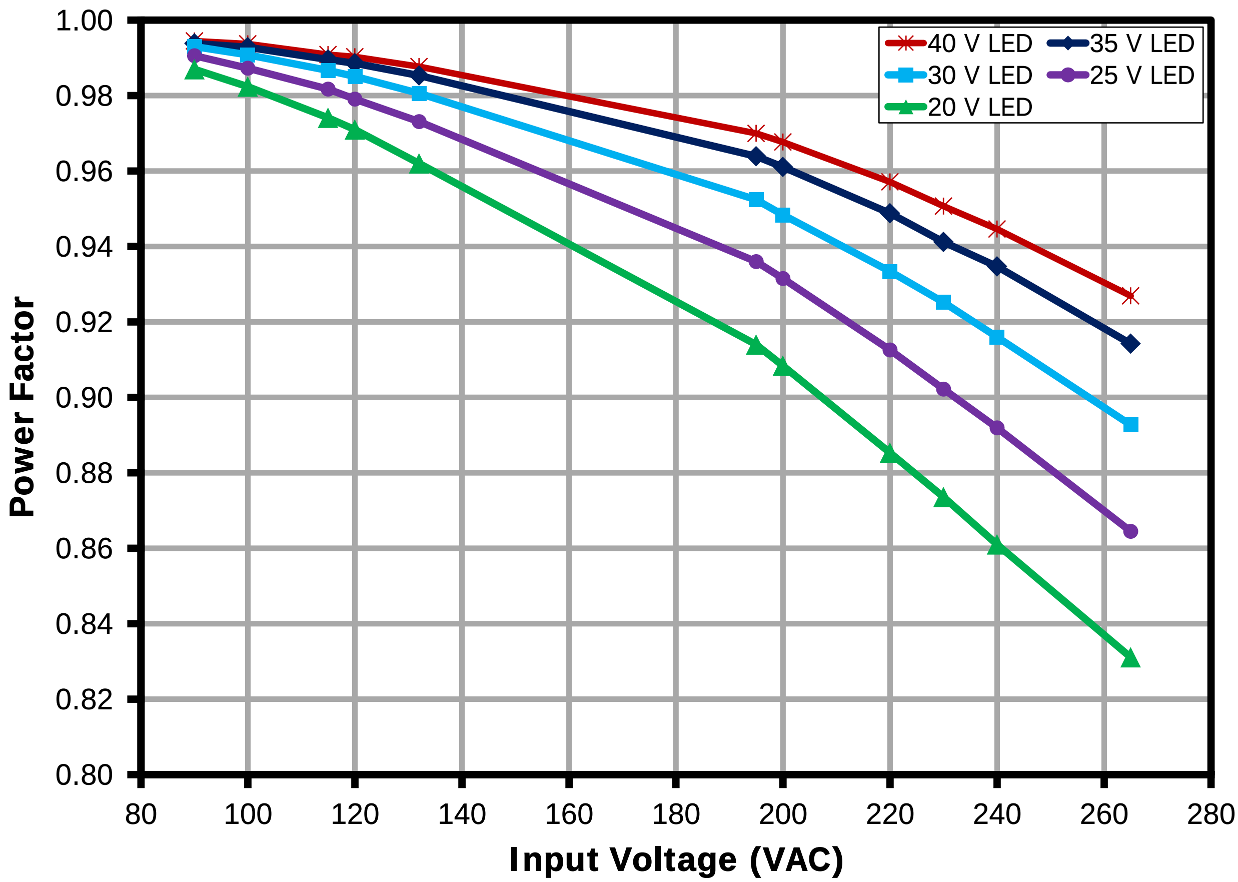

Figure 11 – Power Factor vs. Line and LED Load.

9.4 %ATHD

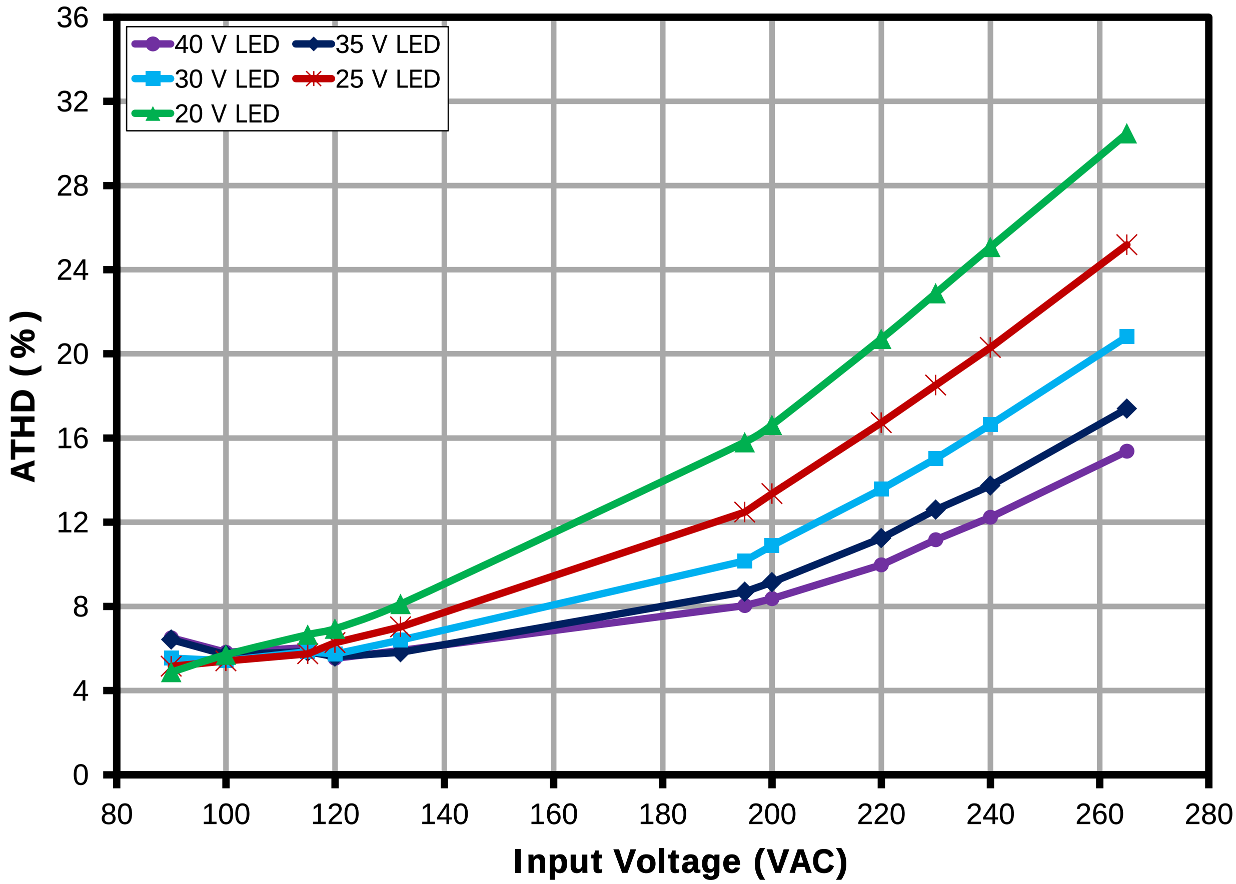

Figure 12 – %ATHD vs. Line and LED Load.

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9.5 Power Input Difference Between 120 V to 230 V

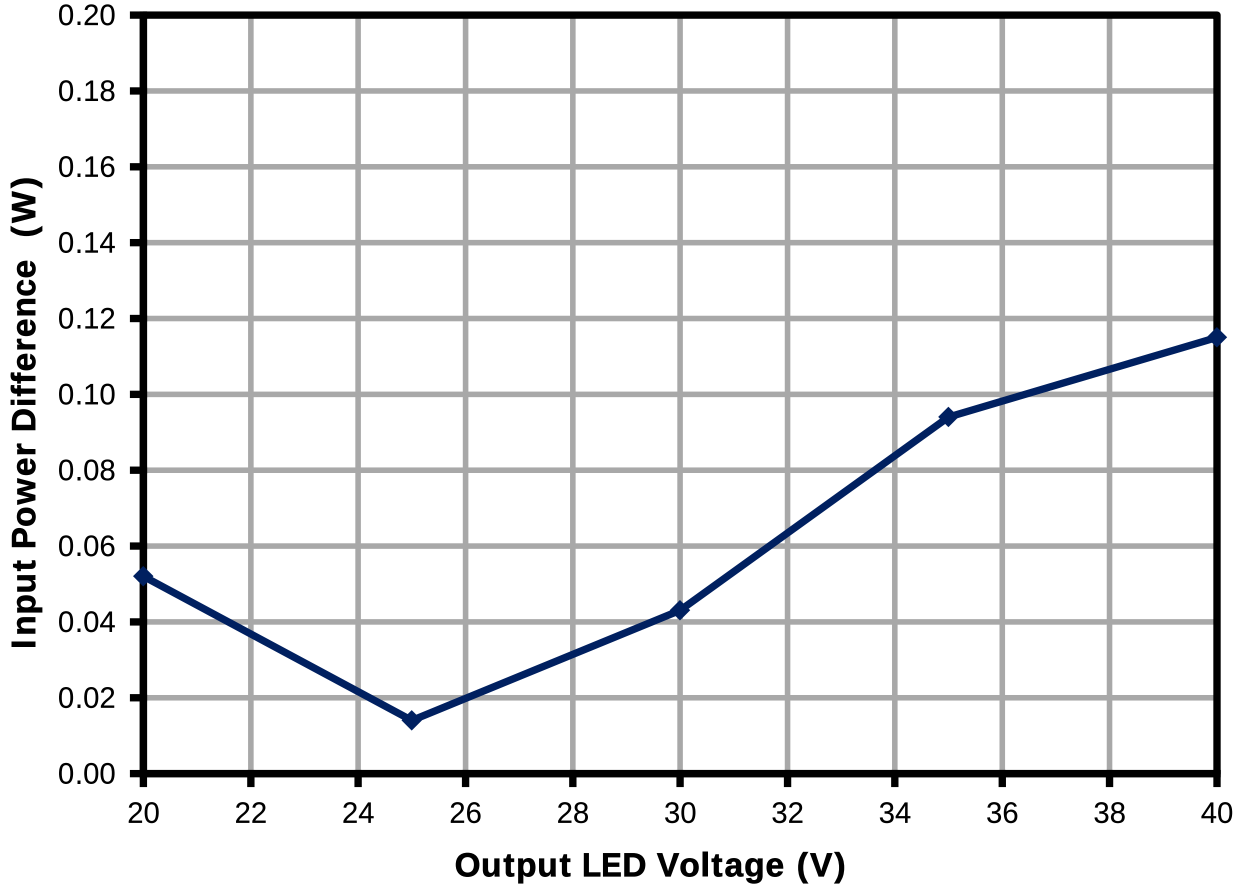

Figure 13 – Power Input Difference between 120 V and 230 V.

9.6 Individual Harmonics Content

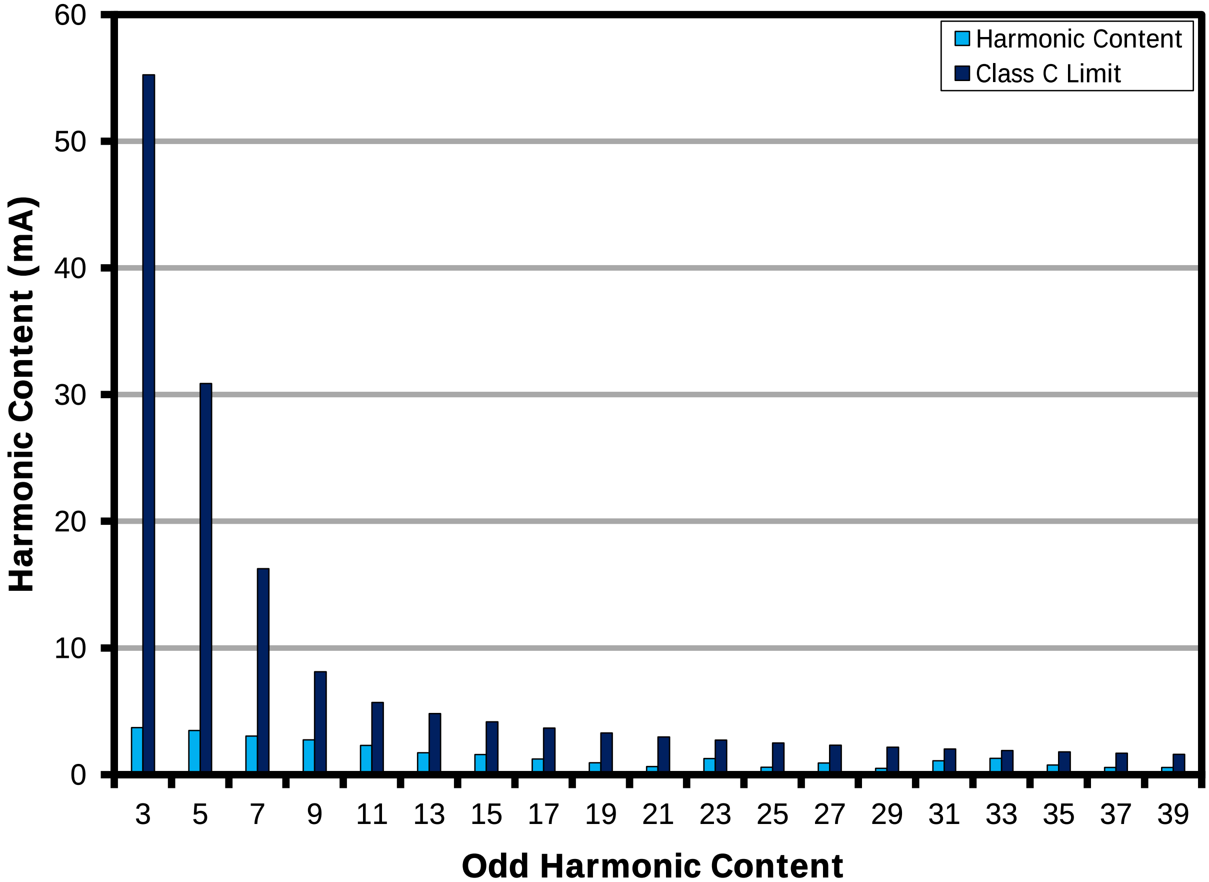

Figure 14 – 40 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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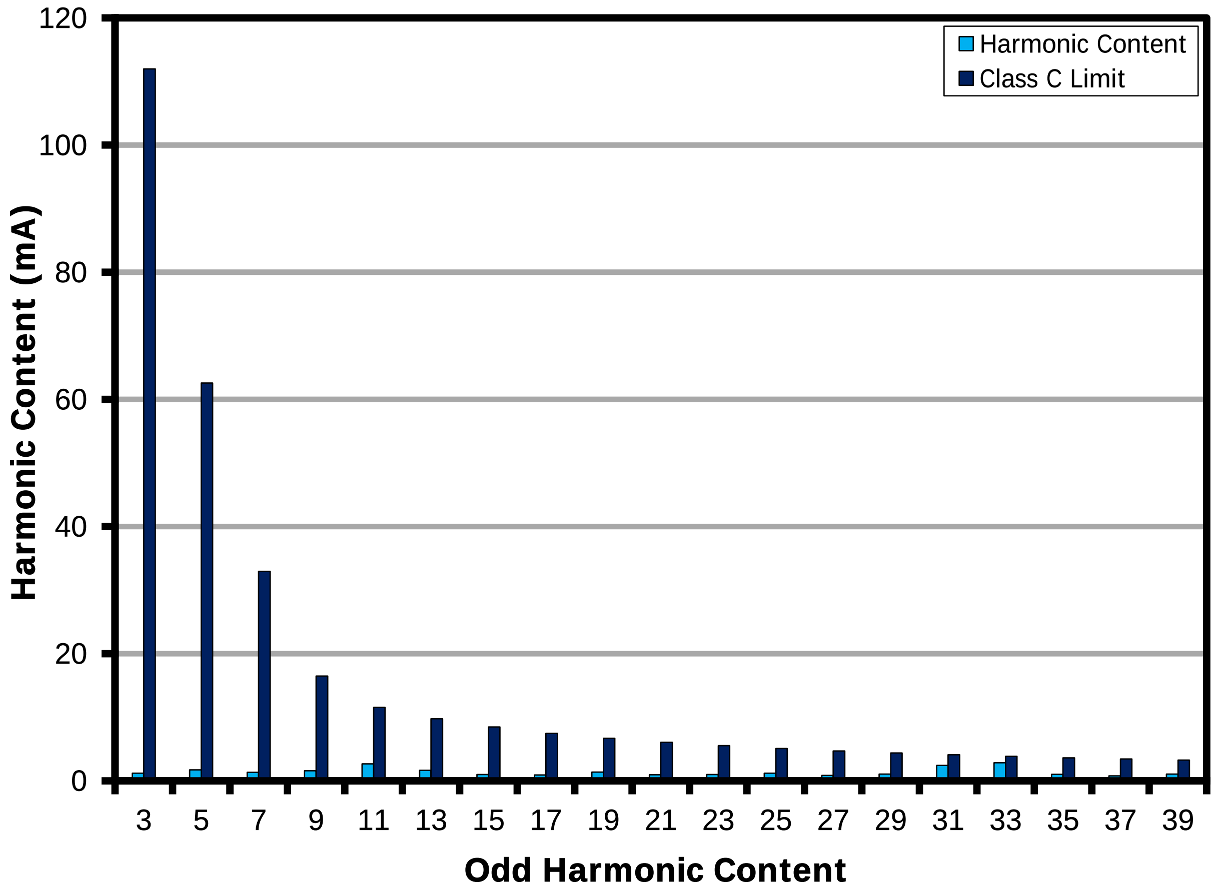

Figure 15 – 40 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

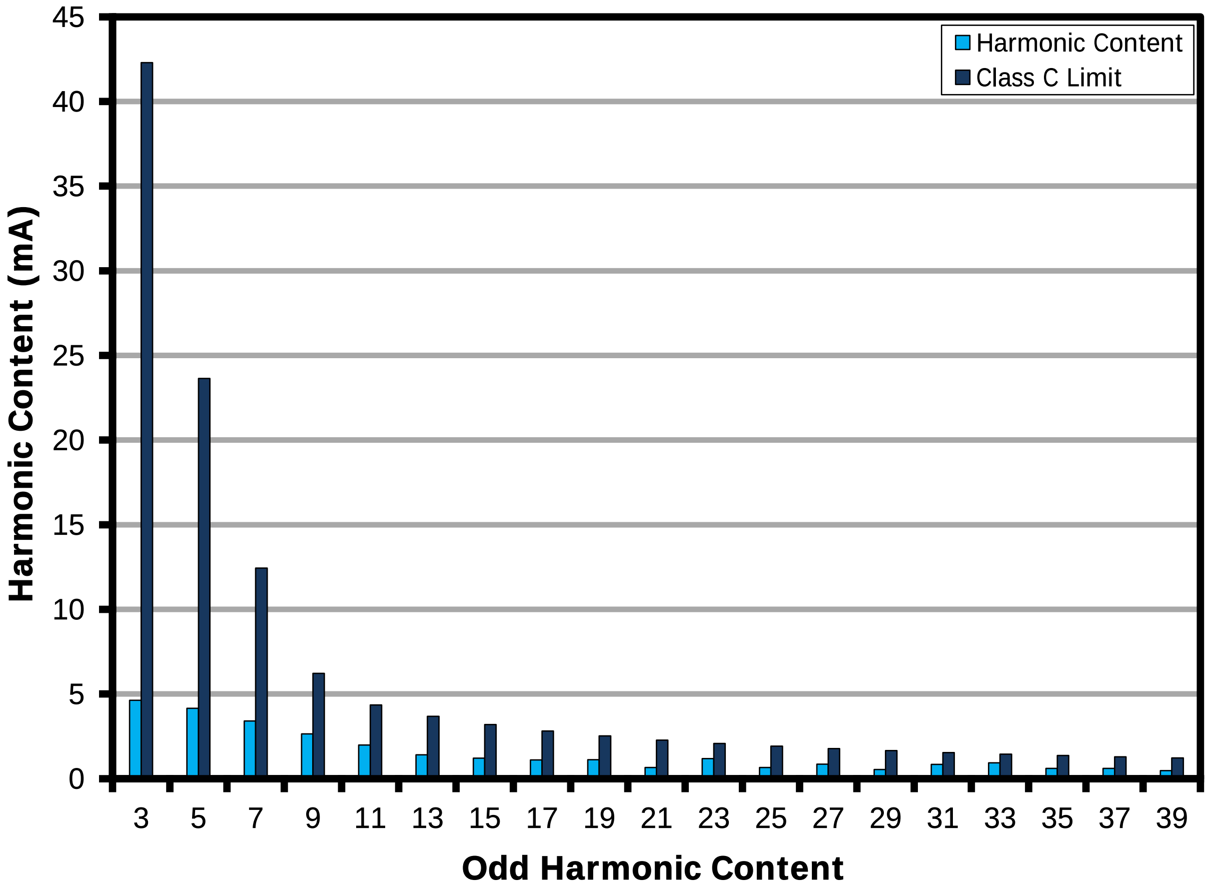

Figure 16 – 30 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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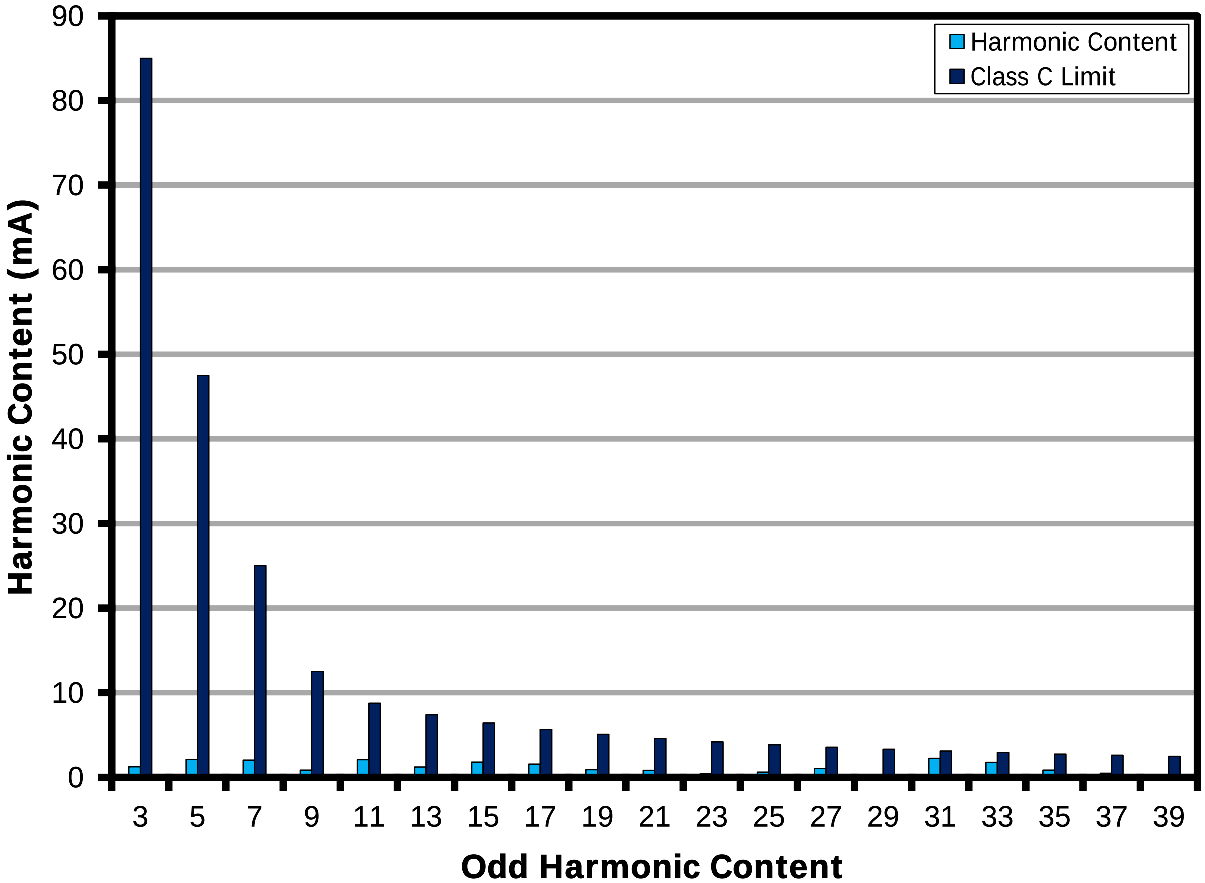

Figure 17 – 30 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

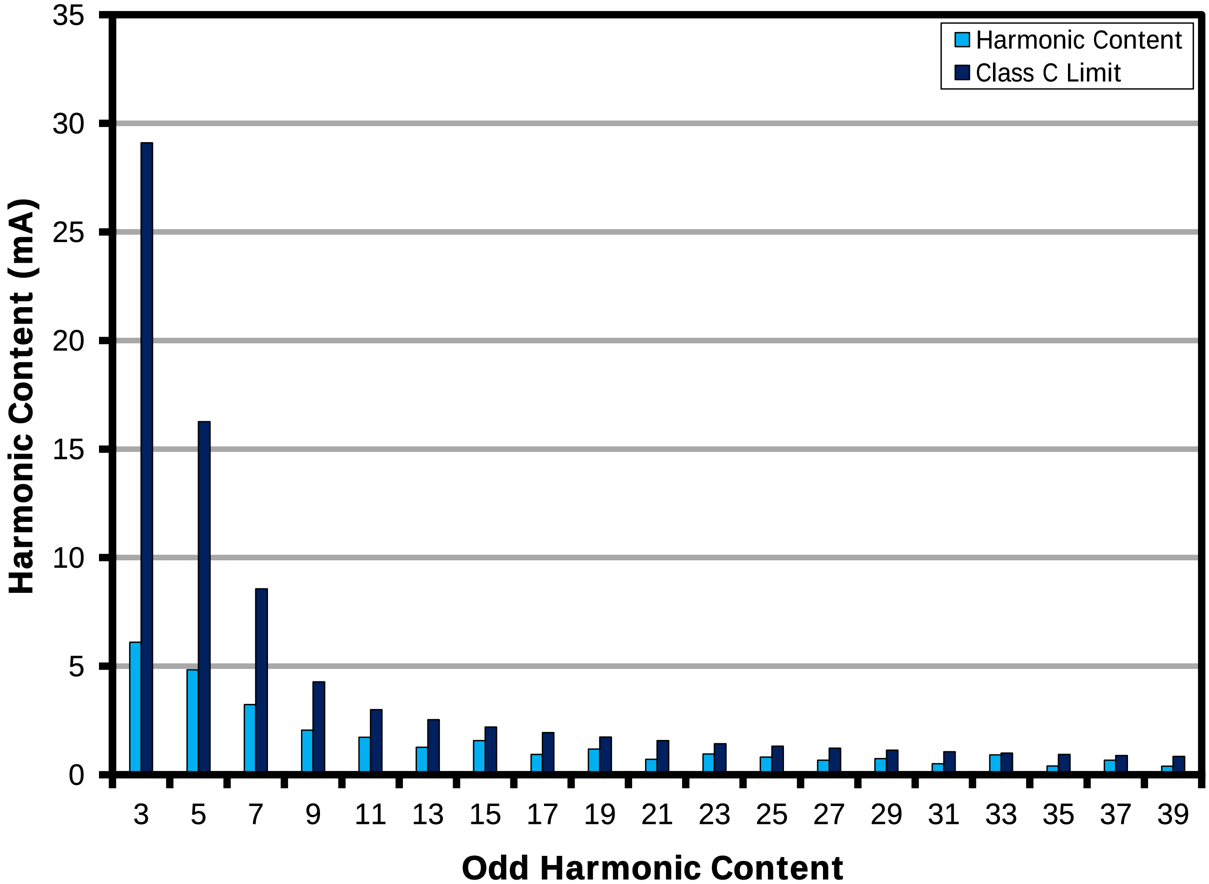

Figure 18 – 20 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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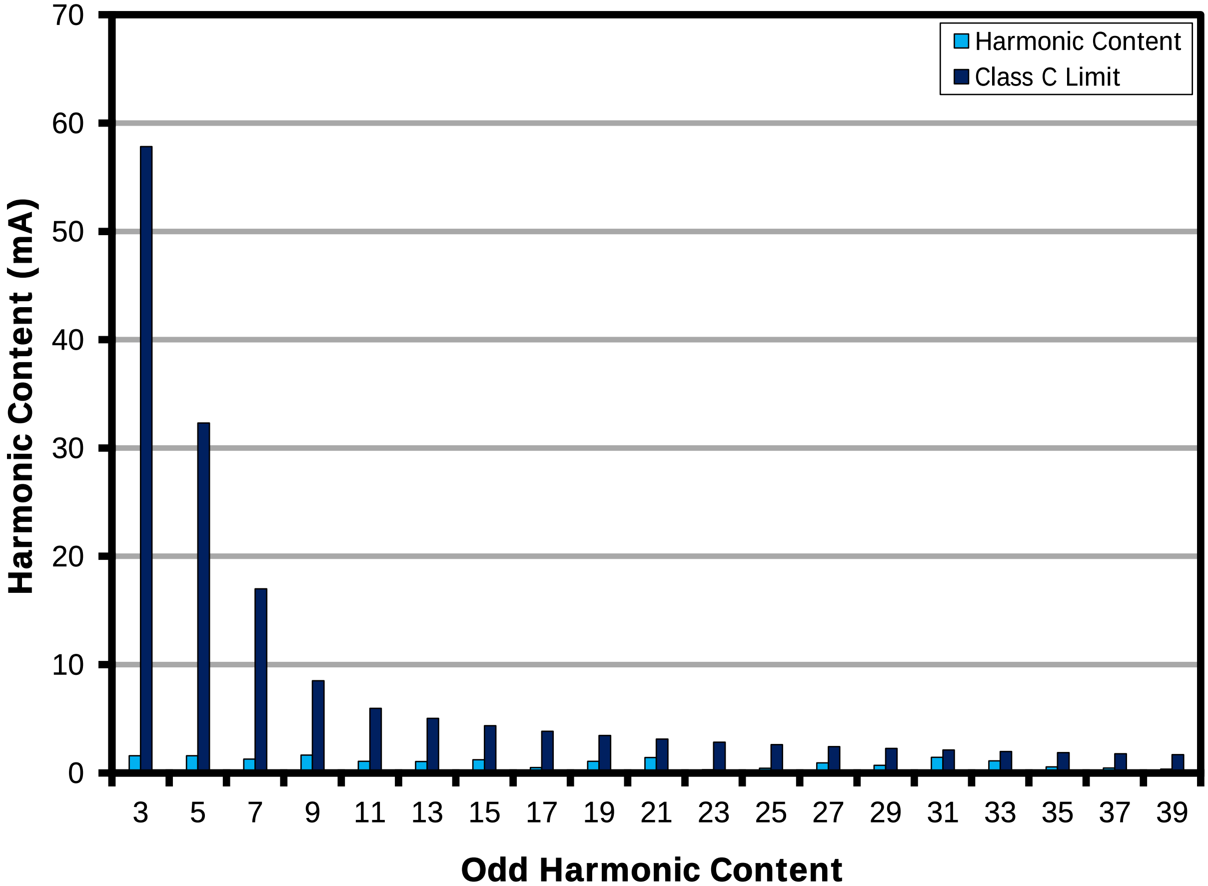

Figure 19 – 20 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

10 Test Data

10.1 Test Data, 40 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.86	186.90	16.70	0.99	6.50	40.09	355.81	14.28	85.52
100	60	99.87	165.30	16.40	0.99	5.82	39.92	353.41	14.13	86.11
115	60	114.87	144.68	16.47	0.99	6.04	39.98	356.77	14.28	86.74
120	60	119.91	137.82	16.37	0.99	5.54	39.95	355.87	14.24	86.99
132	60	131.92	125.31	16.33	0.99	5.91	39.96	356.40	14.26	87.33
195	50	194.93	86.18	16.30	0.97	8.03	39.99	358.37	14.36	88.12
200	50	199.89	84.15	16.28	0.97	8.37	39.98	358.03	14.34	88.09
220	50	219.93	77.32	16.27	0.96	9.98	39.98	358.24	14.35	88.19
230	50	229.95	74.33	16.25	0.95	11.17	39.97	357.84	14.33	88.18
240	50	239.97	71.77	16.27	0.94	12.24	39.98	358.14	14.34	88.16
265	50	264.98	66.23	16.27	0.93	15.38	39.97	357.93	14.33	88.08

10.2 Test Data, 35 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.81	167.14	14.92	0.99	6.43	35.78	356.46	12.78	85.65
100	60	99.83	148.61	14.73	0.99	5.70	35.69	355.13	12.69	86.19
115	60	114.89	129.48	14.72	0.99	5.86	35.71	357.09	12.78	86.78
120	60	119.94	123.67	14.66	0.99	5.61	35.70	356.79	12.76	87.00
132	60	131.92	112.47	14.62	0.99	5.81	35.69	356.86	12.76	87.28
195	50	194.93	77.70	14.60	0.96	8.69	35.72	358.35	12.83	87.88
200	50	199.90	75.90	14.58	0.96	9.15	35.71	358.18	12.82	87.92
220	50	219.93	69.99	14.60	0.95	11.24	35.71	358.36	12.83	87.85
230	50	229.95	67.33	14.57	0.94	12.60	35.69	357.89	12.80	87.87
240	50	239.97	65.12	14.61	0.93	13.74	35.70	358.53	12.83	87.82
265	50	264.98	60.25	14.60	0.91	17.40	35.69	358.05	12.81	87.73

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10.3 Test Data, 30 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.83	143.60	12.81	0.99	5.55	30.42	359.93	10.98	85.71
100	60	99.85	127.46	12.61	0.99	5.42	30.28	357.80	10.86	86.13
115	60	114.86	110.47	12.52	0.99	5.85	30.26	357.80	10.85	86.69
120	60	119.90	105.68	12.48	0.99	5.74	30.24	357.43	10.83	86.79
132	60	131.91	95.92	12.41	0.98	6.40	30.21	356.55	10.80	87.03
195	50	194.93	66.95	12.43	0.95	10.17	30.22	358.01	10.86	87.34
200	50	199.91	65.47	12.41	0.95	10.90	30.21	357.76	10.84	87.38
220	50	219.94	60.39	12.40	0.93	13.56	30.19	357.28	10.82	87.27
230	50	229.96	58.46	12.44	0.93	15.02	30.20	358.20	10.85	87.25
240	50	239.97	56.40	12.40	0.92	16.63	30.17	357.07	10.81	87.17
265	50	264.99	52.59	12.44	0.89	20.82	30.18	357.52	10.82	87.00

10.4 Test Data, 25 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.89	118.21	10.53	0.99	5.15	25.10	357.19	9.00	85.48
100	60	99.91	105.90	10.45	0.99	5.41	25.05	357.07	8.98	85.91
115	60	114.90	91.85	10.36	0.98	5.75	25.02	355.81	8.93	86.24
120	60	119.96	88.09	10.35	0.98	6.27	25.02	355.79	8.93	86.33
132	60	131.94	80.24	10.30	0.97	7.02	25.01	355.34	8.92	86.55
195	50	194.95	56.80	10.36	0.94	12.48	25.02	356.88	8.97	86.58
200	50	199.91	55.66	10.37	0.93	13.36	25.02	357.06	8.98	86.56
220	50	219.95	51.67	10.37	0.91	16.73	25.01	356.67	8.96	86.42
230	50	229.96	49.95	10.36	0.90	18.51	25.01	356.28	8.95	86.38
240	50	239.98	48.53	10.39	0.89	20.30	25.01	356.53	8.96	86.19
265	50	265.00	45.39	10.40	0.86	25.18	25.00	356.35	8.95	86.03

10.5 Test Data, 20 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.88	97.92	8.69	0.99	4.88	20.44	359.07	7.38	84.94
100	60	99.91	87.44	8.58	0.98	5.70	20.36	357.62	7.32	85.34
115	60	114.90	75.99	8.51	0.97	6.66	20.34	355.82	7.28	85.54
120	60	119.95	73.05	8.51	0.97	6.94	20.33	356.13	7.28	85.59
132	60	131.93	66.87	8.49	0.96	8.11	20.33	355.82	7.27	85.71
195	50	194.94	47.94	8.54	0.91	15.80	20.33	35645	7.30	85.45
200	50	199.91	47.02	8.54	0.91	16.62	20.33	356.35	7.30	85.43
220	50	219.94	43.86	8.54	0.89	20.72	20.32	355.83	7.28	85.26
230	50	229.96	42.62	8.56	0.87	22.88	20.32	356.26	7.29	85.15
240	50	239.98	41.42	8.56	0.86	25.07	20.31	355.69	7.27	84.98
265	50	264.99	38.96	8.58	0.83	30.47	20.31	355.63	7.27	84.72

10.6 Test Data, Power Input Difference Between 120 V and 230 V

LED Voltage (V)	Input Power Difference (W)
42.00	0.03
39.00	0.01
35.00	0.01
32.00	0.00
28.00	0.12
25.00	0.12
21.00	0.15

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10.7 Test Data, Harmonic Content at 230 VAC with 40 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	73.24	15.986	11.377
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	73.25			
2	0.08	0.11%		
3	3.71	5.06%	55.25	Pass
5	3.48	4.75%	30.88	Pass
7	3.05	4.16%	16.25	Pass
9	2.75	3.75%	8.13	Pass
11	2.31	3.15%	5.69	Pass
13	1.73	2.36%	4.81	Pass
15	1.59	2.17%	4.17	Pass
17	1.24	1.69%	3.68	Pass
19	0.93	1.27%	3.29	Pass
21	0.64	0.87%	2.98	Pass
23	1.27	1.73%	2.72	Pass
25	0.59	0.81%	2.50	Pass
27	0.91	1.24%	2.32	Pass
29	0.50	0.68%	2.16	Pass
31	1.10	1.50%	2.02	Pass
33	1.28	1.75%	1.90	Pass
35	0.76	1.04%	1.79	Pass
37	0.57	0.78%	1.69	Pass
39	0.56	0.76%	1.60	Pass

10.8 Test Data, Harmonic Content at 115 VAC with 40 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	% THD
115	60	144.68	16.468	6.04
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	136.89			
2	0.16	0.12%		
3	1.19	0.87%	111.98	Pass
5	1.70	1.24%	62.58	Pass
7	1.34	0.98%	32.94	Pass
9	1.59	1.16%	16.47	Pass
11	2.65	1.94%	11.53	Pass
13	1.65	1.21%	9.75	Pass
15	0.98	0.72%	8.45	Pass
17	0.92	0.67%	7.46	Pass
19	1.37	1.00%	6.67	Pass
21	0.96	0.70%	6.04	Pass
23	1.00	0.73%	5.51	Pass
25	1.20	0.88%	5.07	Pass
27	0.86	0.63%	4.70	Pass
29	1.05	0.77%	4.37	Pass
31	2.40	1.75%	4.09	Pass
33	2.83	2.07%	3.84	Pass
35	1.02	0.75%	3.62	Pass
37	0.79	0.58%	3.43	Pass
39	1.05	0.77%	3.25	Pass

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10.9 Test Data, Harmonic Content at 230 VAC with 30 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	58.49	12.440	15.015
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	57.14			
2	0.06	0.11%		
3	4.63	8.10%	42.30	Pass
5	4.16	7.28%	23.64	Pass
7	3.40	5.95%	12.44	Pass
9	2.64	4.62%	6.22	Pass
11	1.99	3.48%	4.35	Pass
13	1.41	2.47%	3.68	Pass
15	1.21	2.12%	3.19	Pass
17	1.10	1.93%	2.82	Pass
19	1.12	1.96%	2.52	Pass
21	0.66	1.16%	2.28	Pass
23	1.19	2.08%	2.08	Pass
25	0.66	1.16%	1.92	Pass
27	0.85	1.49%	1.77	Pass
29	0.54	0.95%	1.65	Pass
31	0.84	1.47%	1.54	Pass
33	0.94	1.65%	1.45	Pass
35	0.60	1.05%	1.37	Pass
37	0.61	1.07%	1.29	Pass
39	0.47	0.82%	1.23	Pass

10.10 Test Data, Harmonic Content at 115 VAC with 30 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60	110.26	12.498	5.825
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	109.34			
2	0.19	0.17%		
3	1.25	1.14%	84.99	Pass
5	2.11	1.93%	47.49	Pass
7	2.03	1.86%	25.00	Pass
9	0.84	0.77%	12.50	Pass
11	2.09	1.91%	8.75	Pass
13	1.22	1.12%	7.40	Pass
15	1.80	1.65%	6.42	Pass
17	1.56	1.43%	5.66	Pass
19	0.90	0.82%	5.06	Pass
21	0.83	0.76%	4.58	Pass
23	0.45	0.41%	4.18	Pass
25	0.61	0.56%	3.85	Pass
27	1.04	0.95%	3.56	Pass
29	0.32	0.29%	3.32	Pass
31	2.25	2.06%	3.10	Pass
33	1.77	1.62%	2.92	Pass
35	0.84	0.77%	2.75	Pass
37	0.48	0.44%	2.60	Pass
39	0.28	0.26%	2.47	Pass

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10.11 Test Data, Harmonic Content at 230 VAC with 20 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	42.63	8.560	22.82
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	40.70			
2	0.04	0.10%		
3	6.10	14.99%	29.10	Pass
5	4.83	11.87%	16.26	Pass
7	3.23	7.94%	8.56	Pass
9	2.05	5.04%	4.28	Pass
11	1.73	4.25%	3.00	Pass
13	1.26	3.10%	2.54	Pass
15	1.57	3.86%	2.20	Pass
17	0.94	2.31%	1.94	Pass
19	1.18	2.90%	1.73	Pass
21	0.71	1.74%	1.57	Pass
23	0.96	2.36%	1.43	Pass
25	0.81	1.99%	1.32	Pass
27	0.67	1.65%	1.22	Pass
29	0.74	1.82%	1.14	Pass
31	0.51	1.25%	1.06	Pass
33	0.92	2.26%	1.00	Pass
35	0.40	0.98%	0.94	Pass
37	0.67	1.65%	0.89	Pass
39	0.39	0.96%	0.85	Pass

10.12 Test Data, Harmonic Content at 115 VAC with 20 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60	75.97	8.503	6.588
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	74.99			
2	0.10	0.13%		
3	1.59	2.12%	57.82	Pass
5	1.58	2.11%	32.31	Pass
7	1.28	1.71%	17.01	Pass
9	1.64	2.19%	8.50	Pass
11	1.08	1.44%	5.95	Pass
13	1.04	1.39%	5.04	Pass
15	1.21	1.61%	4.36	Pass
17	0.50	0.67%	3.85	Pass
19	1.08	1.44%	3.45	Pass
21	1.41	1.88%	3.12	Pass
23	0.29	0.39%	2.85	Pass
25	0.44	0.59%	2.62	Pass
27	0.93	1.24%	2.42	Pass
29	0.70	0.93%	2.26	Pass
31	1.45	1.93%	2.11	Pass
33	1.12	1.49%	1.98	Pass
35	0.55	0.73%	1.87	Pass
37	0.46	0.61%	1.77	Pass
39	0.36	0.48%	1.68	Pass

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11 Thermal Performance

11.1 Thermal Performance Scan – Open Frame Unit

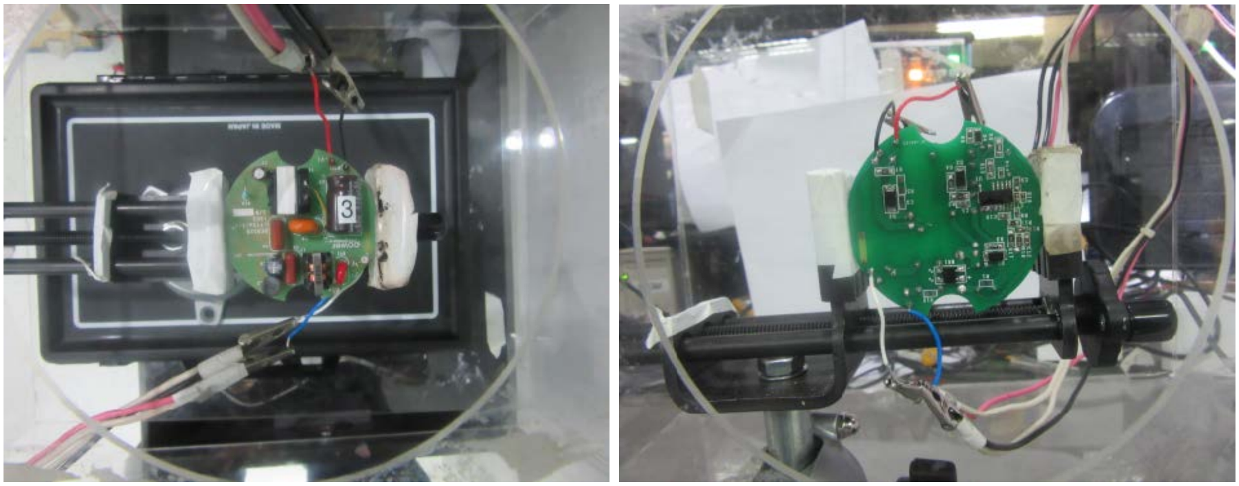

Figure 20 – Test Set-up Picture - Open Frame.

Unit in open frame was placed inside an acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR thermal camera.

11.1.1 Thermal Scan

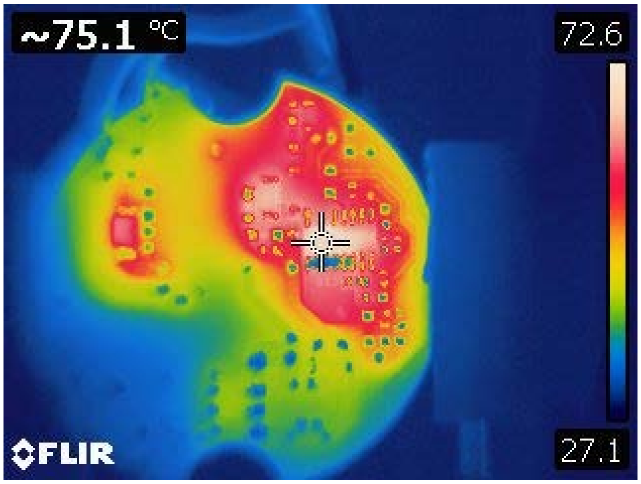

Figure 21 – 230 VAC, 40 V LED Load.
Spot 1: LYT5226D (U1): 75.1 ºC.

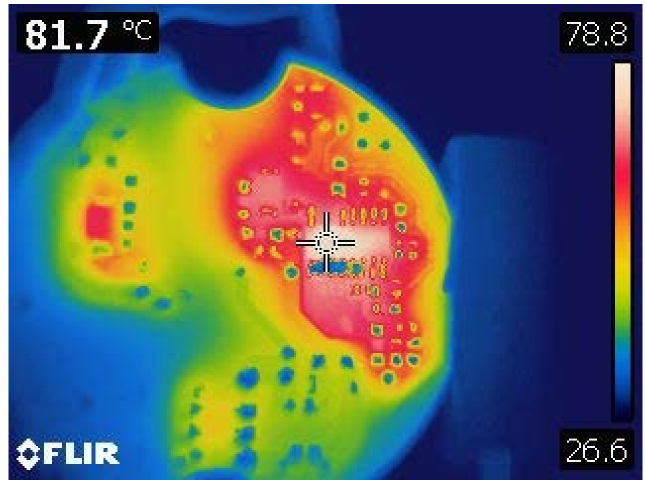

Figure 22 – 115 VAC, 40 V LED Load.
Spot 1: LYT5226D (U1): 81.7 ºC.

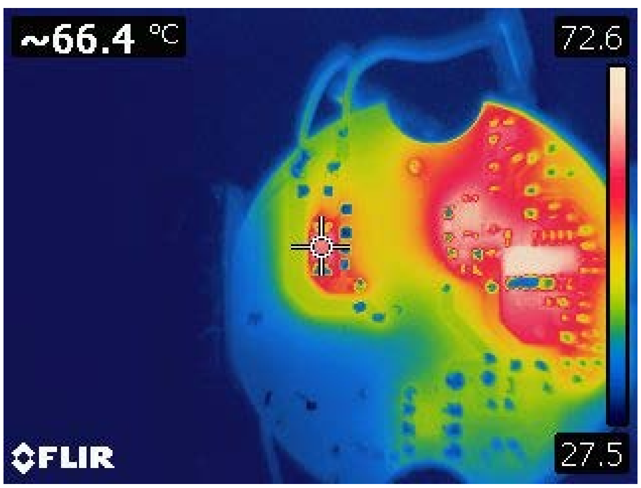

Figure 23 – 230 VAC, 40 V LED Load.
Spot 1: Output Diode (D3): 66.4 ºC.

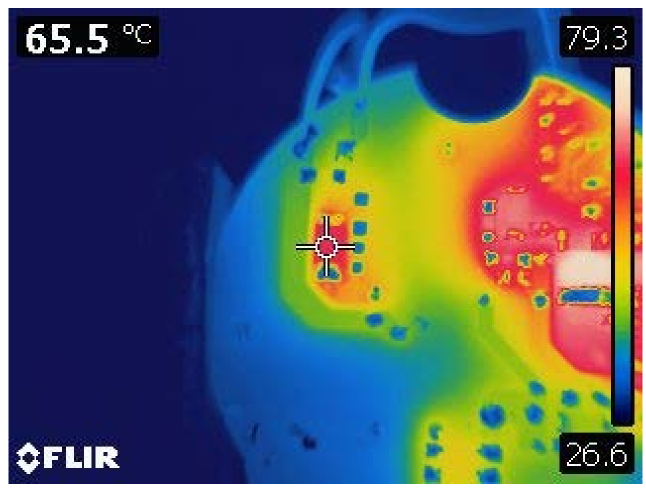

Figure 24 – 115 VAC, 40 V LED Load.
Spot 1: Output Diode (D3): 65.5 ºC.

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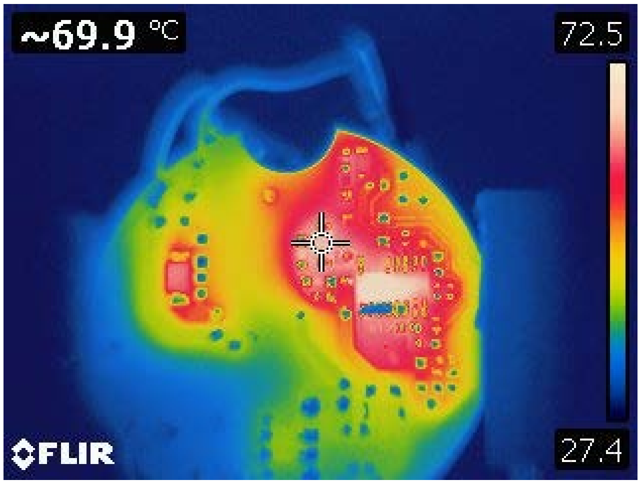

Figure 25 – 230 VAC, 40 V LED Load.
Spot 1: Snubber Diode (D2): 69.9 ºC.

Figure 26 – 115 VAC, 40 V LED Load.
Spot 1: Snubber Diode (D2): 71.6 ºC.

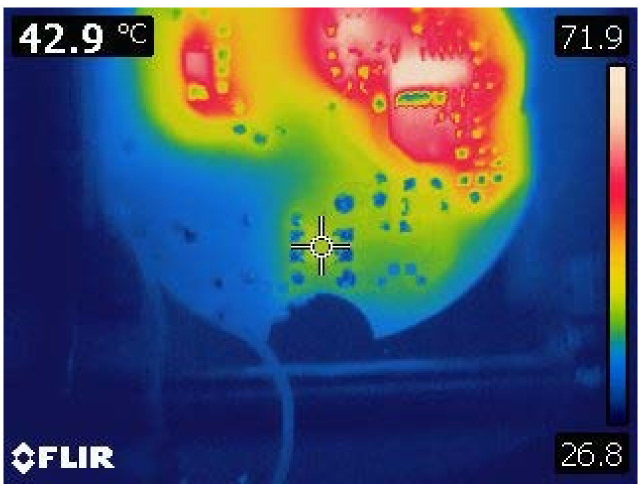

Figure 27 – 230 VAC, 40 V LED Load.
Spot 1: Bridge Diode (BR1): 42.9 ºC.

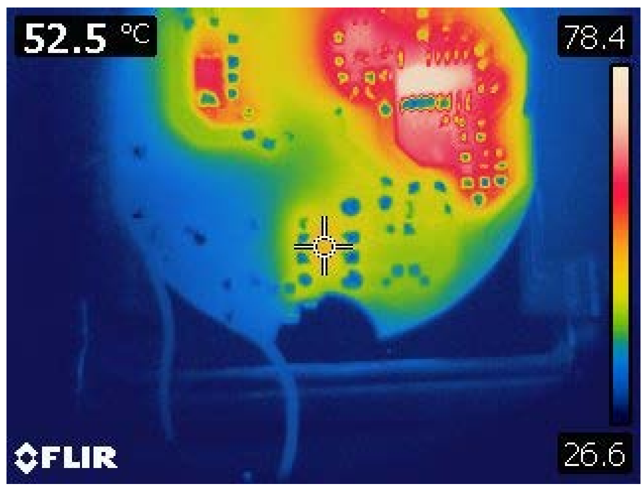

Figure 28 – 115 VAC, 40 V LED Load.
Spot 1: Bridge Diode (BR1): 52.5 ºC.

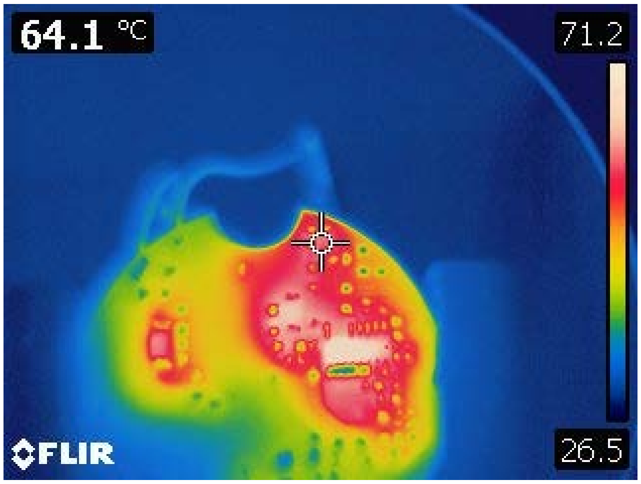

Figure 29 – 230 VAC, 40 V LED Load.
Spot 1: Bias Diode (D4): 64.1 ºC.

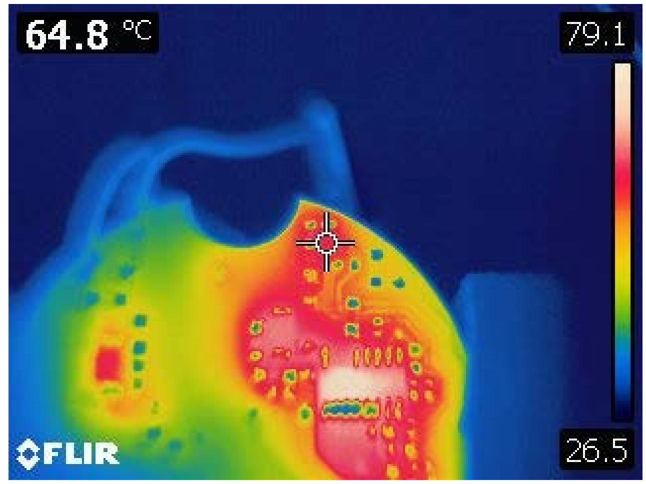

Figure 30 – 115 VAC, 40 V LED Load.
Spot 1: Bias Diode (D4): 64.8 ºC.

11.1.2 Thermal Scan at the Top Side

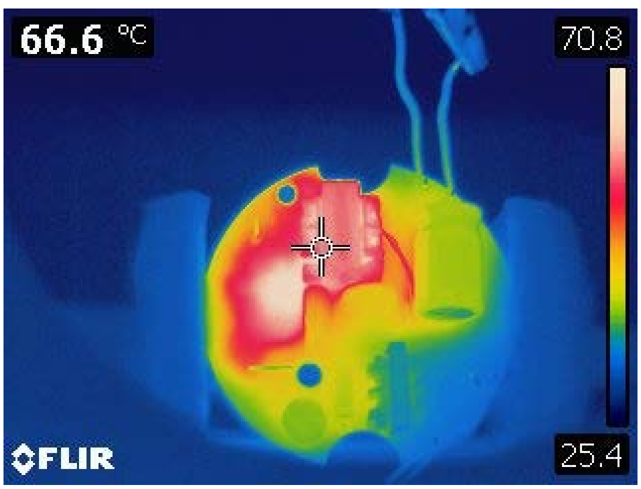

Figure 31 – 230 VAC, 40 V LED Load.
Spot 1: Transformer (T1): 66.6 ºC.

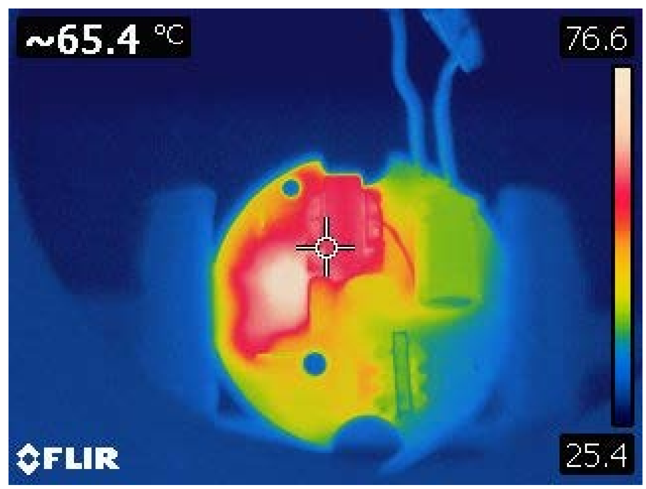

Figure 32 –115 VAC, 40 V LED Load.
Spot 1: Transformer (T1): 65.4 ºC.

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11.2 Thermal Performance at 85 ºC

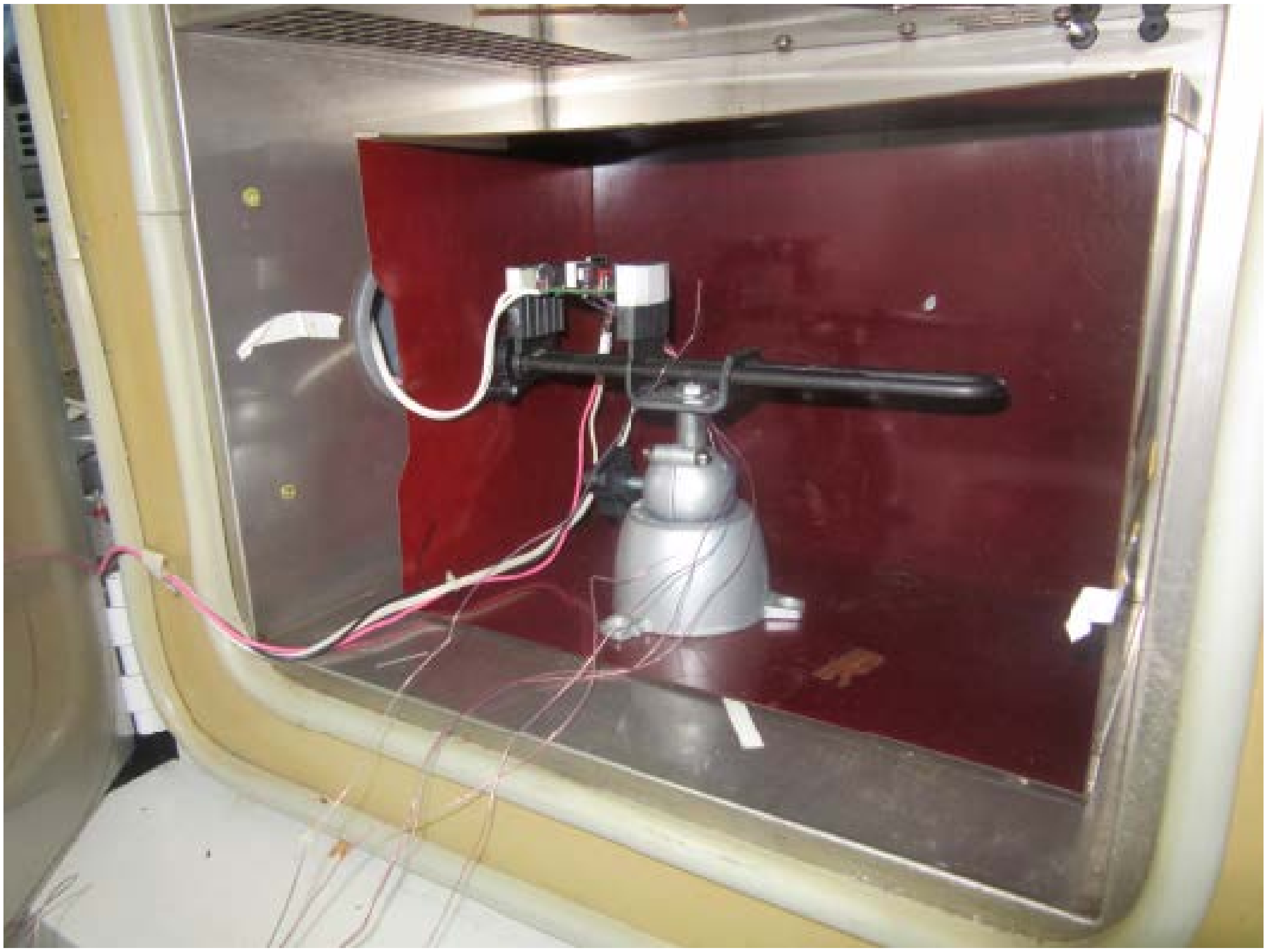

Figure 33 – Test Set-up Picture Thermal at 85 ºC Ambient - Open Frame.

Unit in open frame was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 85 ºC. Temperature was measured using Type T thermocouple.

11.2.1 Thermal Performance at 230 VAC with a 40 V LED Load

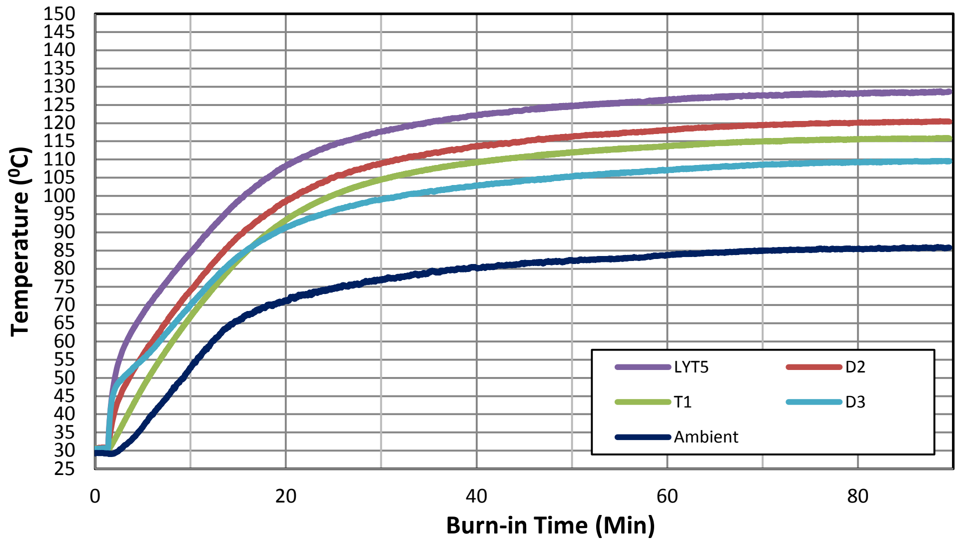

Figure 34 – Component Temperature at 230 VAC, 85 ºC Ambient

Measurement	Ambient	D2	T1	LYTSwitch-5	D3
Maximum (ºC)	86.0	120.6	115.9	128.8	109.6
Final (ºC)	85.8	120.4	115.8	128.6	109.5

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11.2.2 Thermal Performance at 120 VAC with a 40 V LED Load

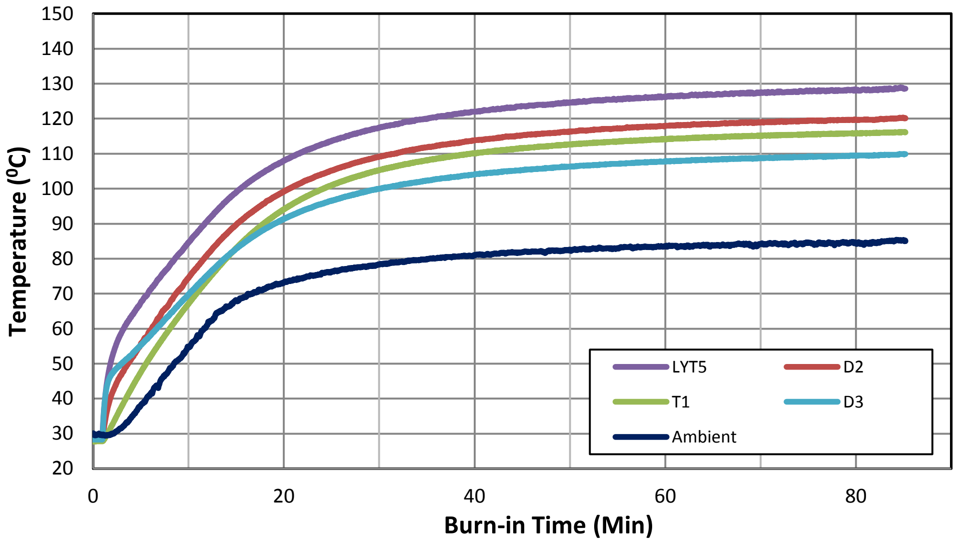

Figure 35 – Component Temperature at 230VAC, 85 ºC Ambient.

Measurement	Ambient	D2	T1	LYTSwitch-5	D3
Maximum (ºC)	85.4	120.3	116.2	128.9	109.9
Final (ºC)	85.0	120.1	116.1	128.6	109.9

12 Waveforms

12.1 Input Voltage and Input Current Waveforms

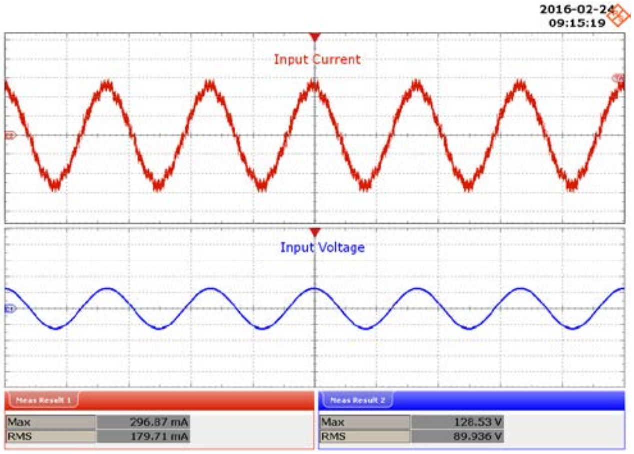

Figure 36 – 90 VAC, 40 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

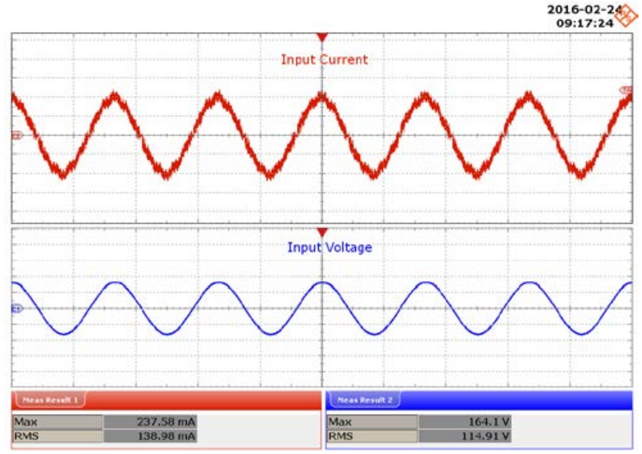

Figure 37 – 115 VAC, 40 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

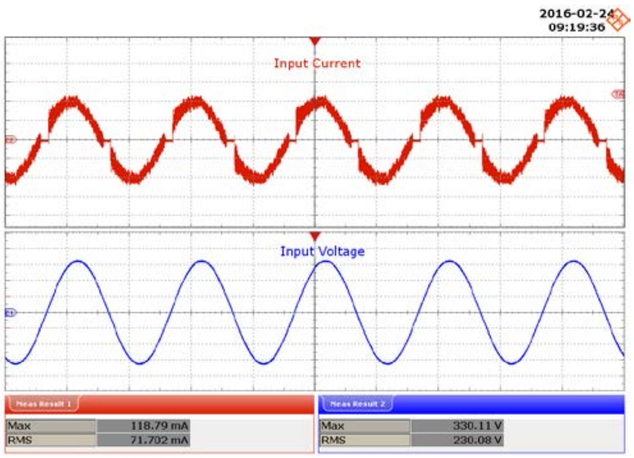

Figure 38 – 230 VAC, 40 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

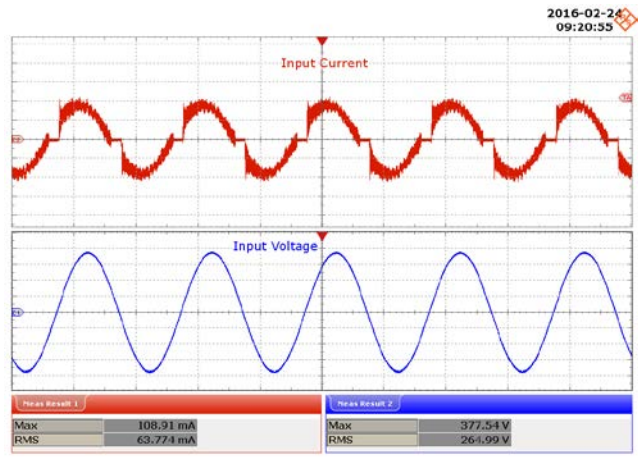

Figure 39 – 265 VAC, 40 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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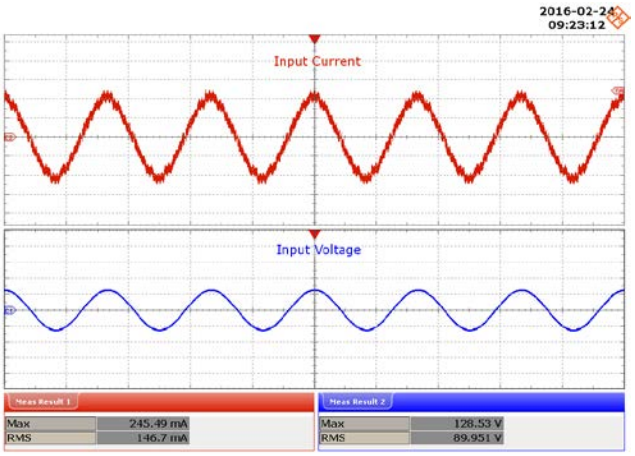

Figure 40 – 90 VAC, 32 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

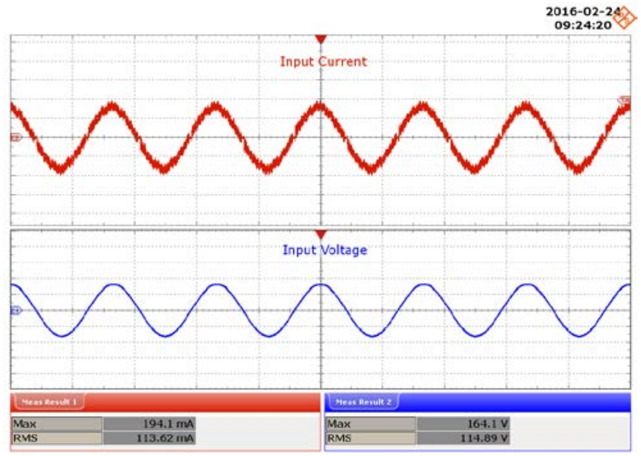

Figure 41 – 115 VAC, 32 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

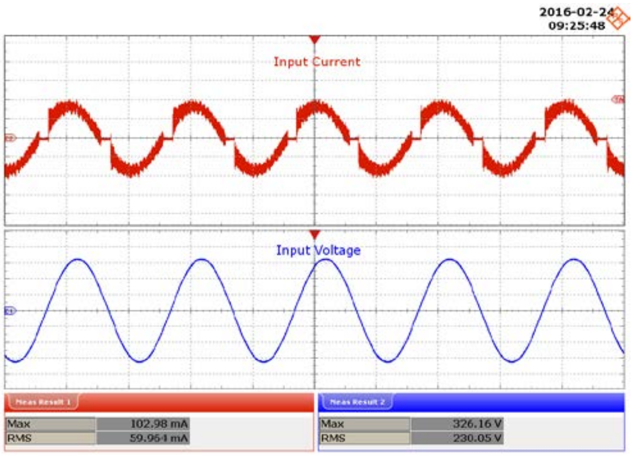

Figure 42 – 230 VAC, 32 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

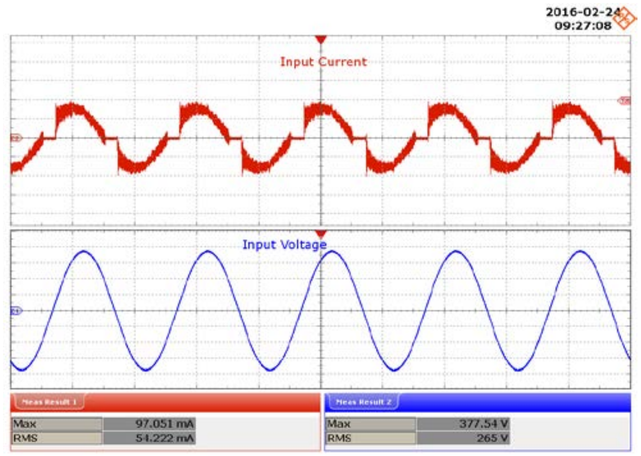

Figure 43 – 265 VAC, 32 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

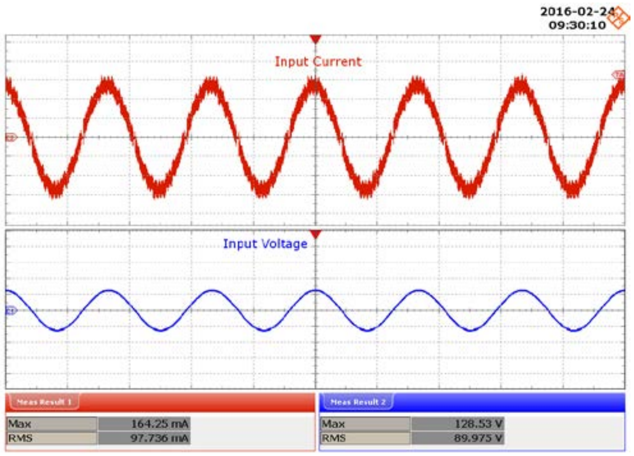

Figure 44 – 90 VAC, 21 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

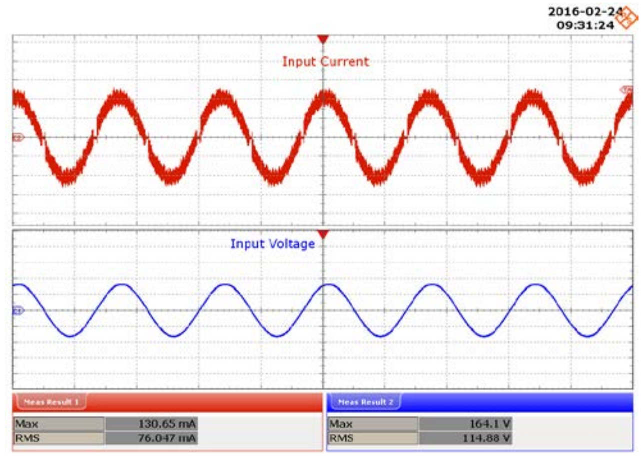

Figure 45 – 115 VAC, 21 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

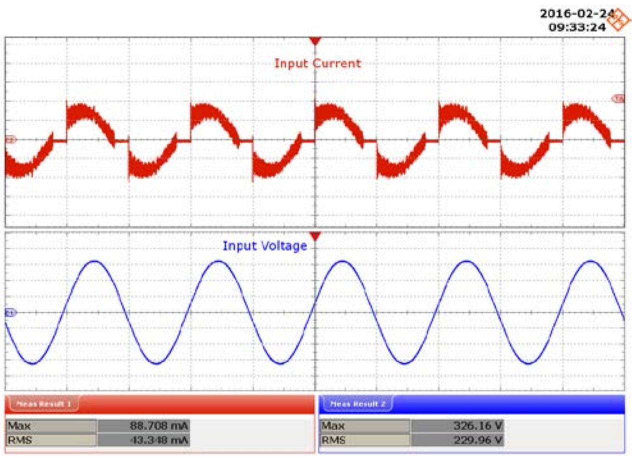

Figure 46 – 230 VAC, 20 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

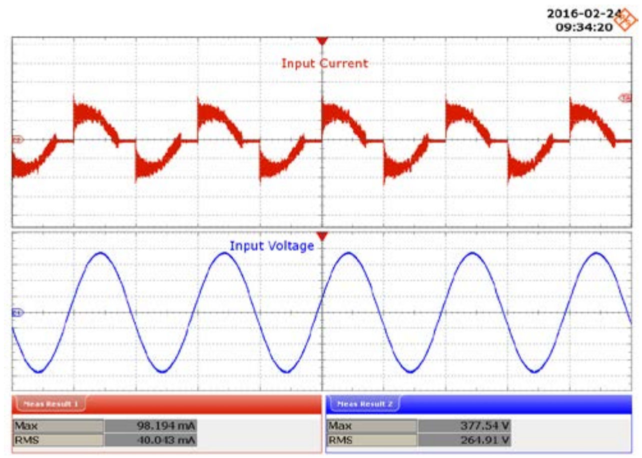

Figure 47 – 265 VAC, 20 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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12.2 Output Current Rise

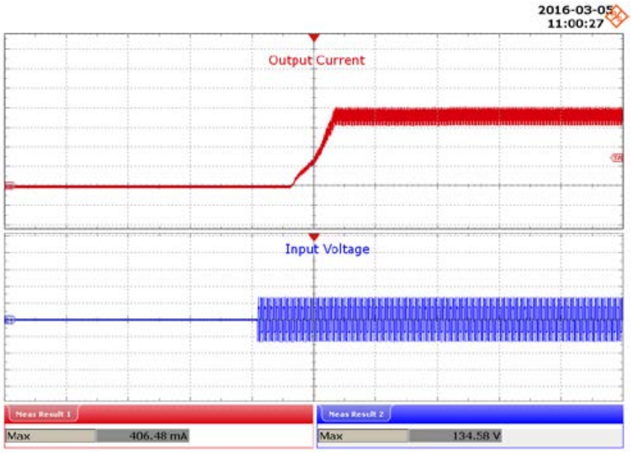

Figure 48 – 90 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

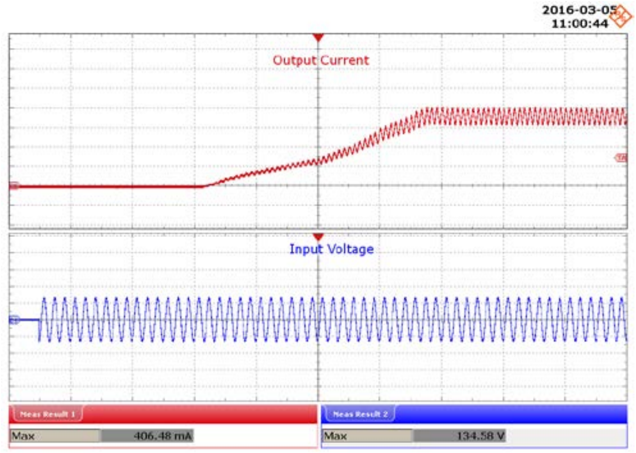

Figure 49 – 90 VAC, 40 V LED Load, Zoom View.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

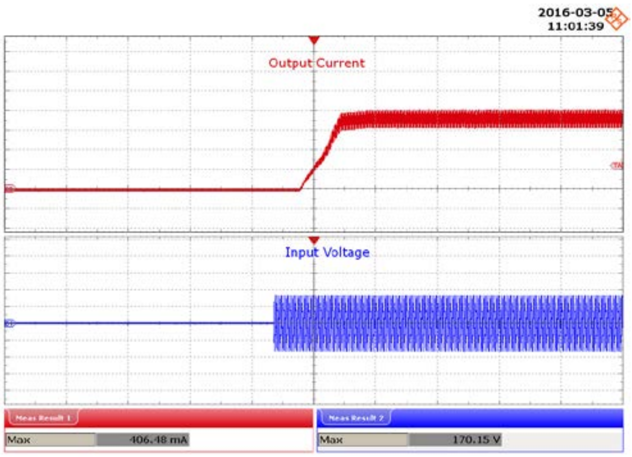

Figure 50 – 115 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

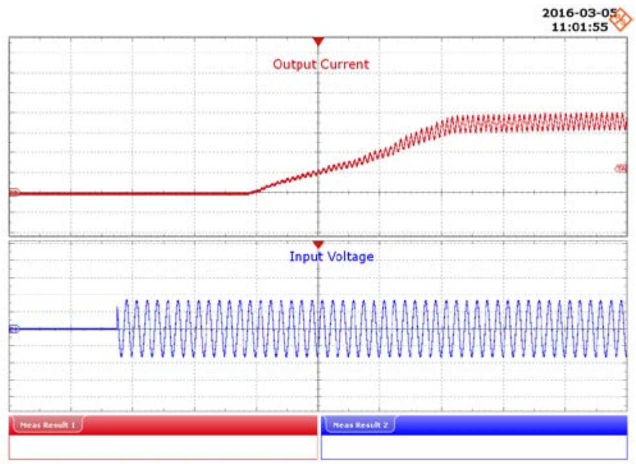

Figure 51 – 115 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

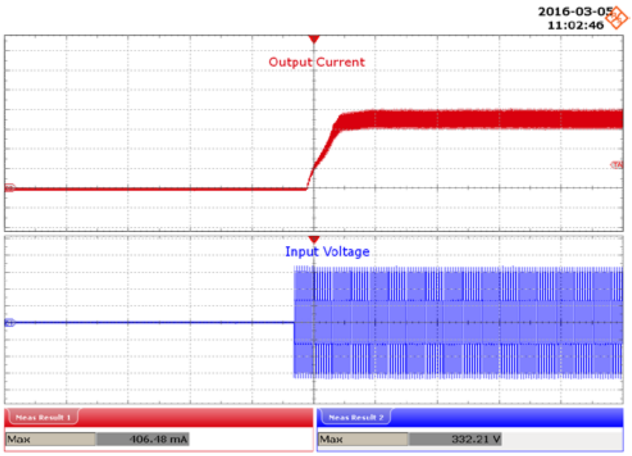

Figure 52 – 230 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

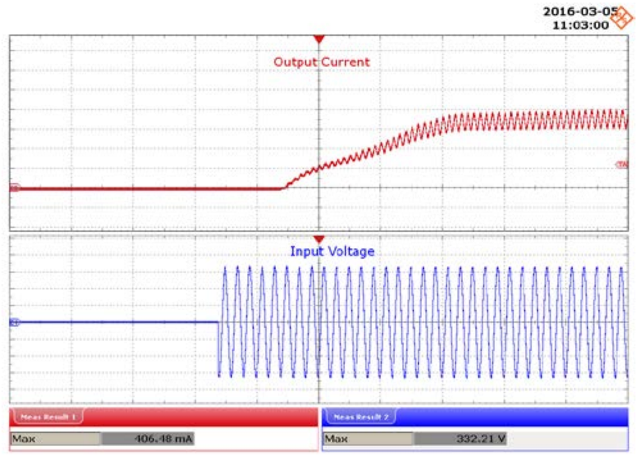

Figure 53 – 230 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

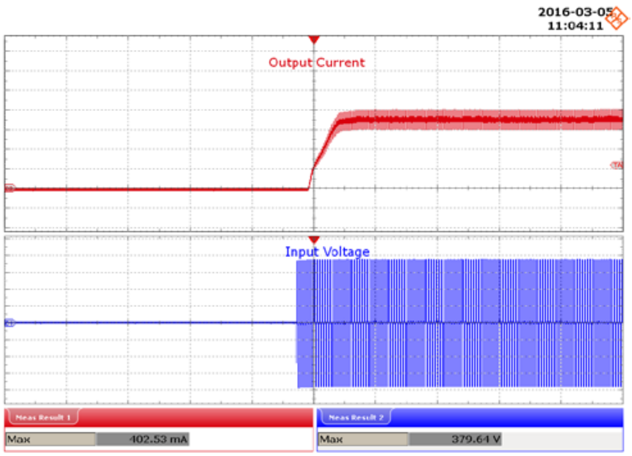

Figure 54 – 265 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

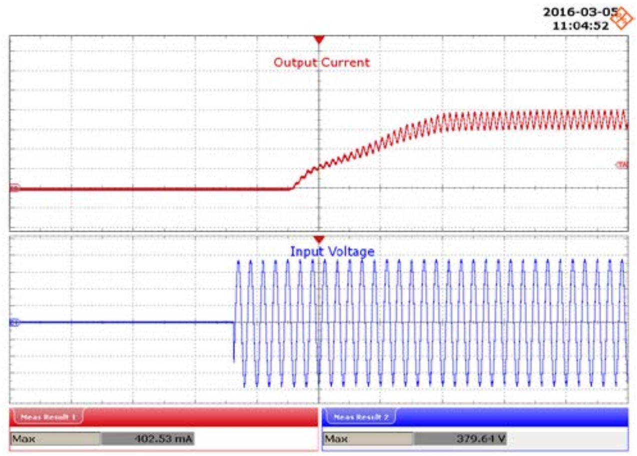

Figure 55 – 265 VAC, 40 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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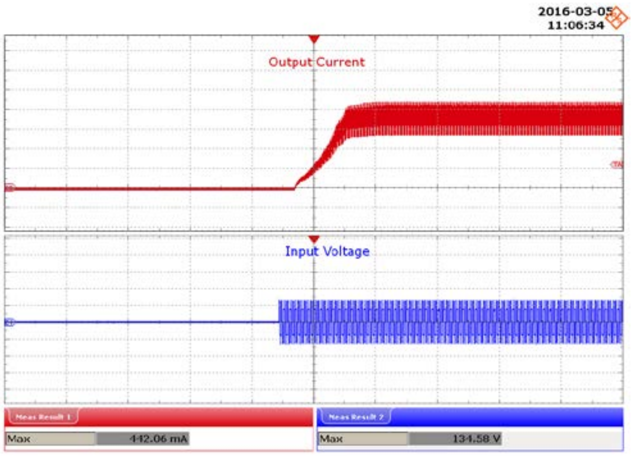

Figure 56 – 90 VAC, 20 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

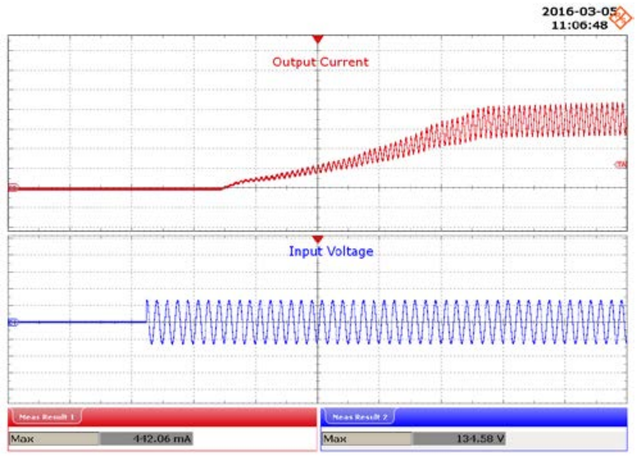

Figure 57 – 115 VAC, 20 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

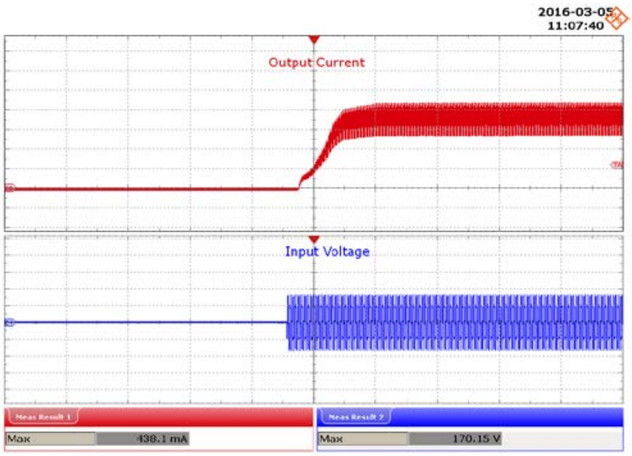

Figure 58 – 115 VAC, 20 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

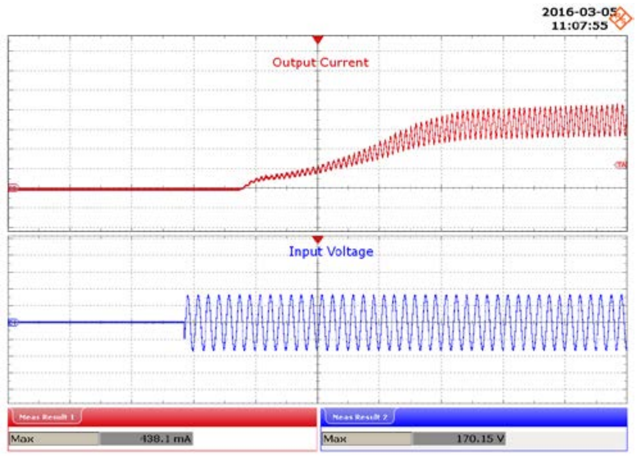

Figure 59 – 115 VAC, 20 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

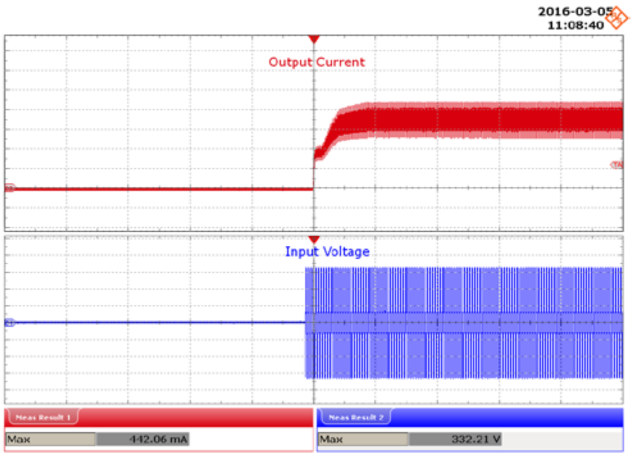

Figure 60 – 230 VAC, 21 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

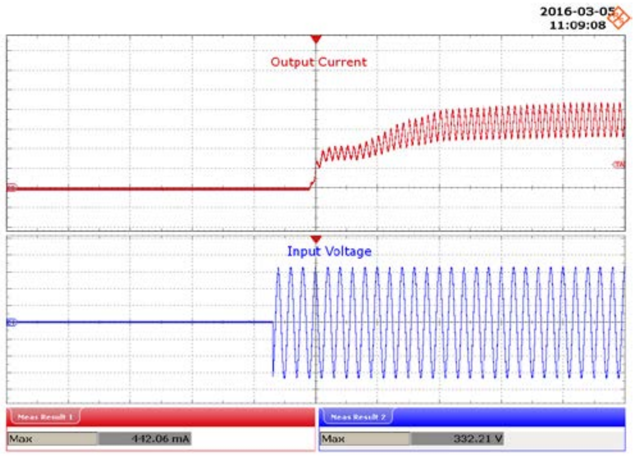

Figure 61 – 230 VAC, 21 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

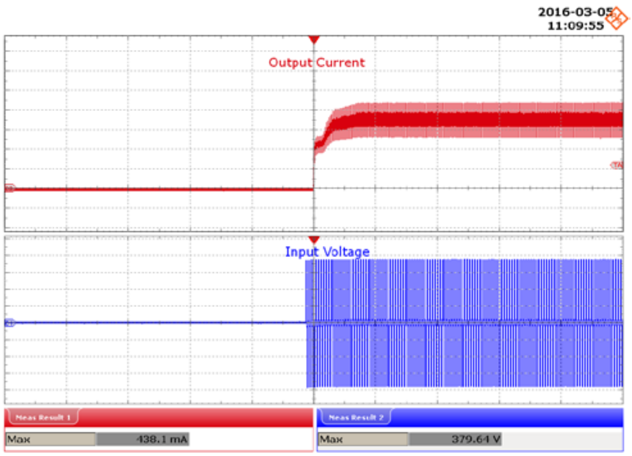

Figure 62 – 265 VAC, 21 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 500 ms / div.

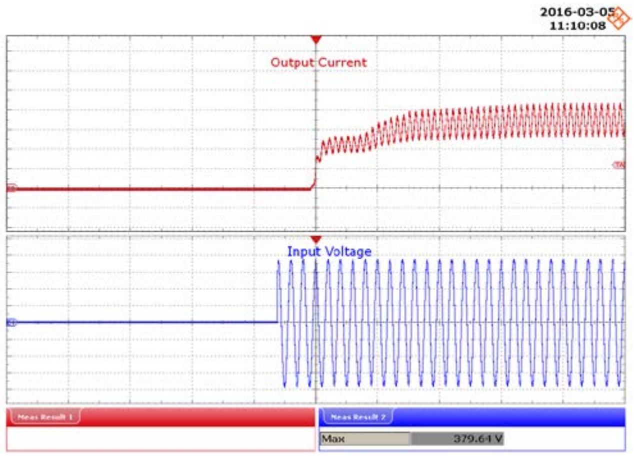

Figure 63 – 265 VAC, 21 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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12.3 Output Current Fall

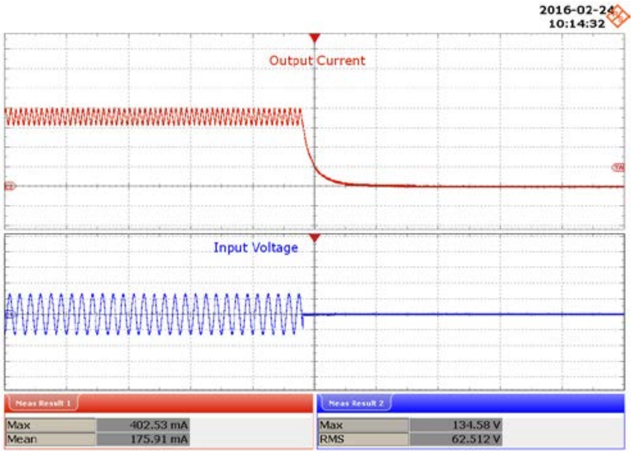

Figure 64 – 90 VAC, 40 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

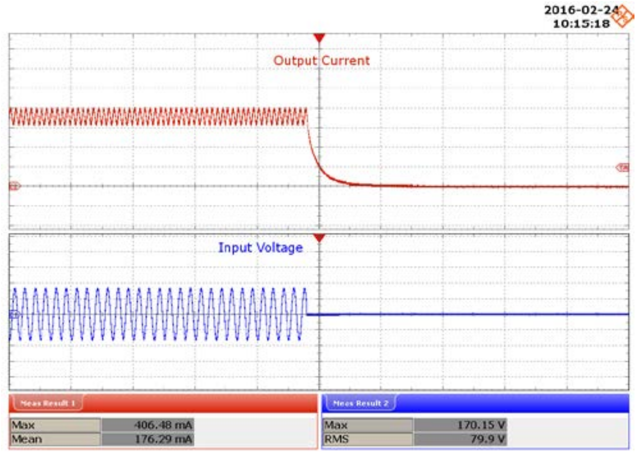

Figure 65 – 115 VAC, 40 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

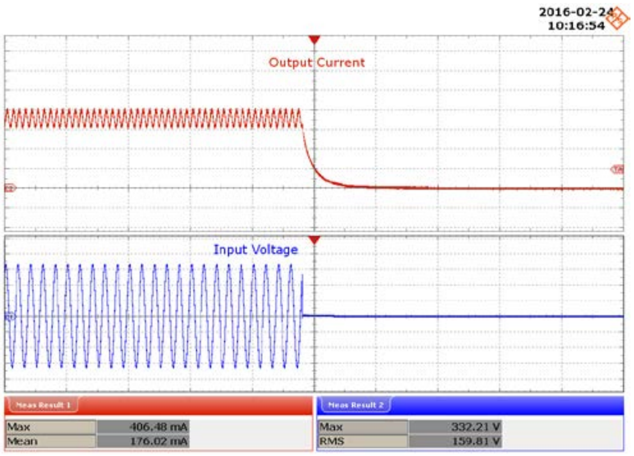

Figure 66 – 230 VAC, 40 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

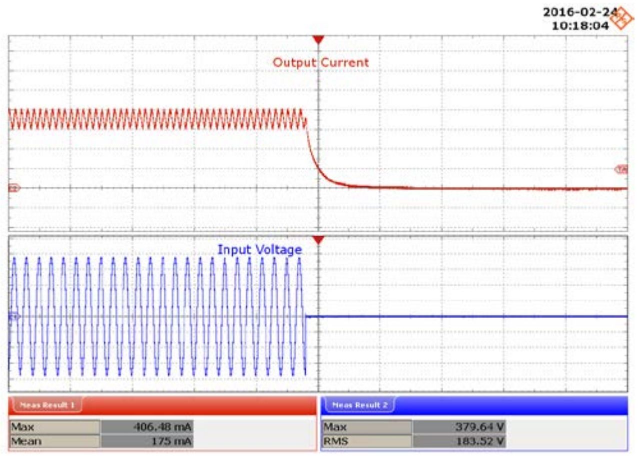

Figure 67 – 265 VAC, 40 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

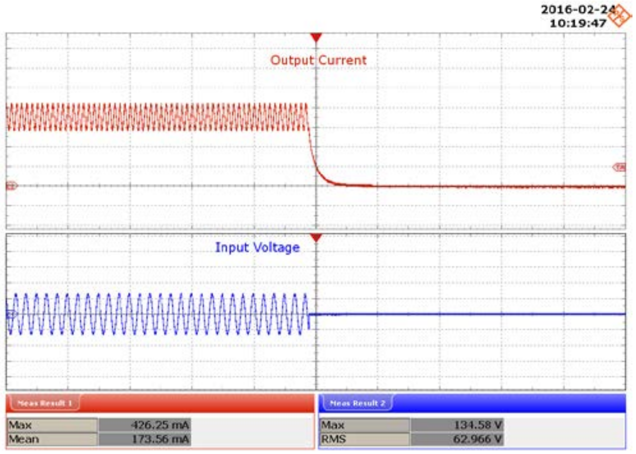

Figure 68 – 90 VAC, 21 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

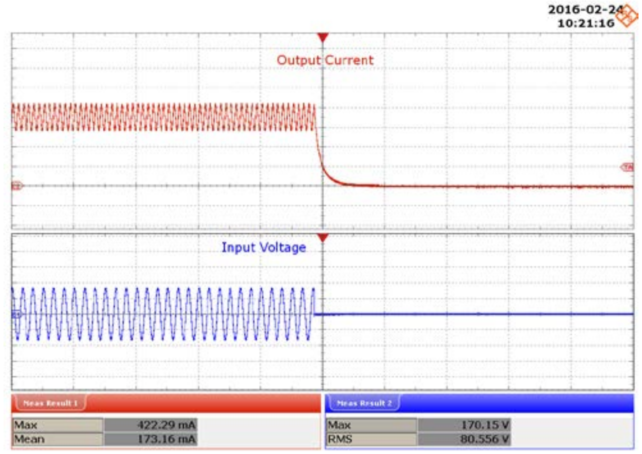

Figure 69 – 115 VAC, 21 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

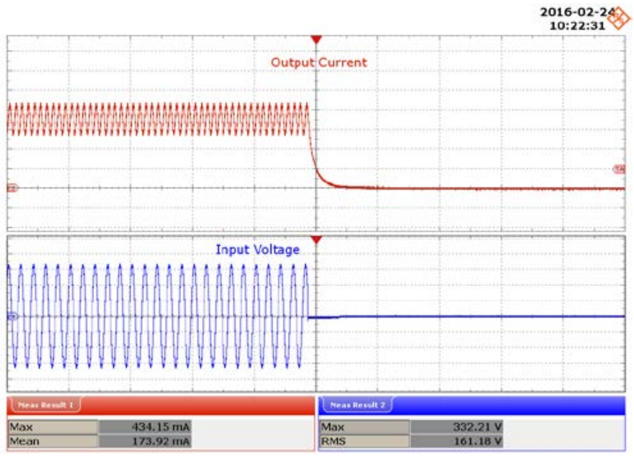

Figure 70 – 230 VAC, 21 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

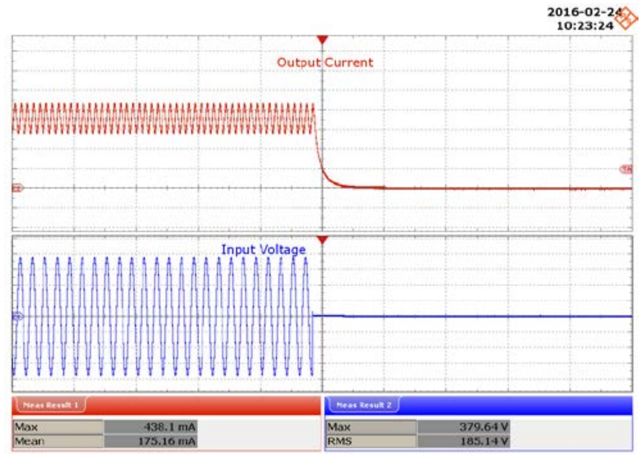

Figure 71 – 265 VAC, 21 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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12.4 Drain Voltage and Current in Normal Operation

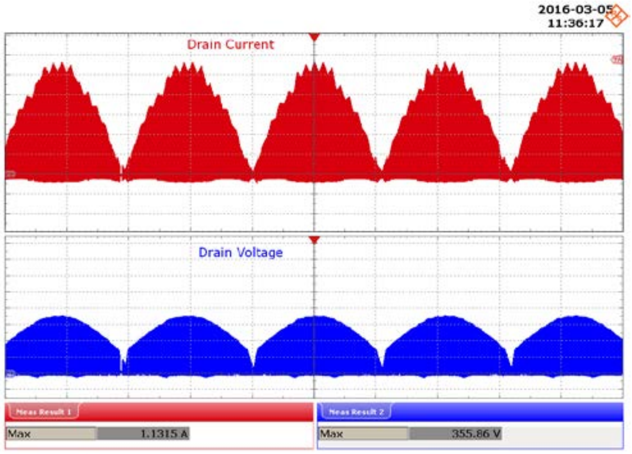

Figure 72 – 90 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

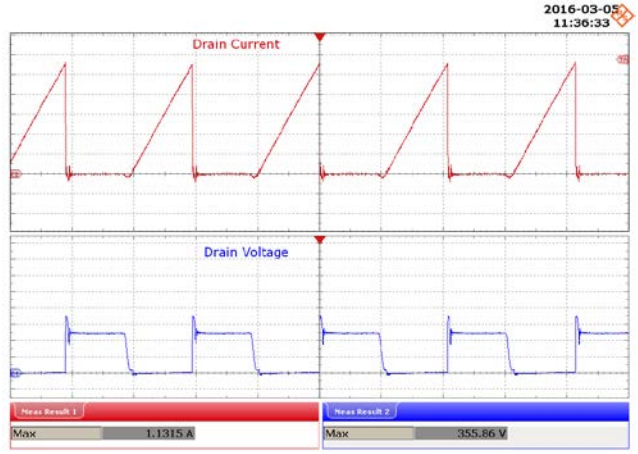

Figure 73 – 90 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

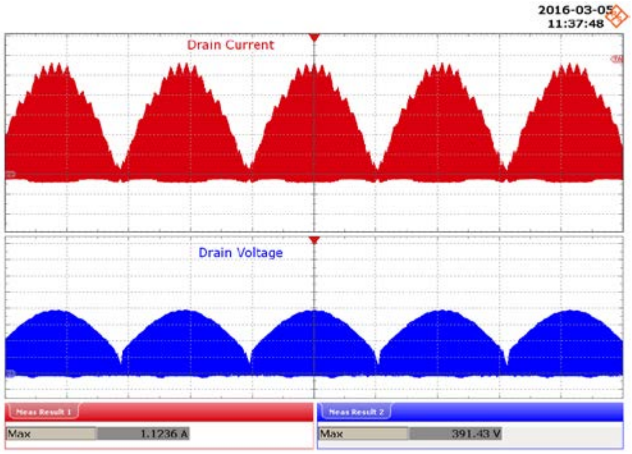

Figure 74 – 115 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

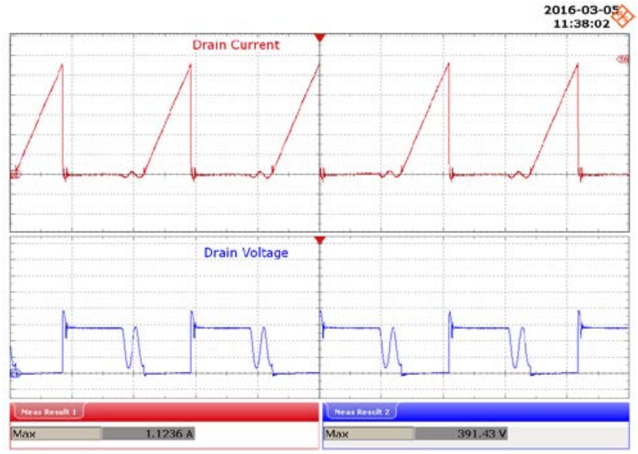

Figure 75 – 115 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

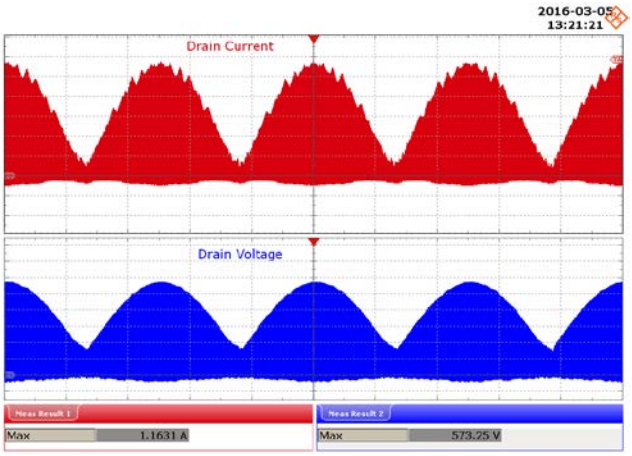

Figure 76 – 230 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

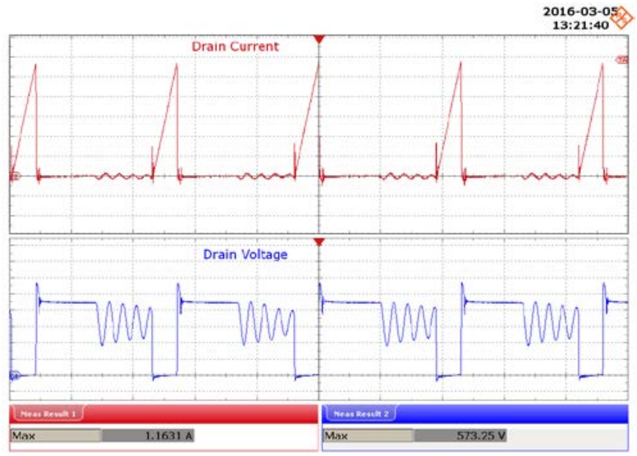

Figure 77 – 230 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

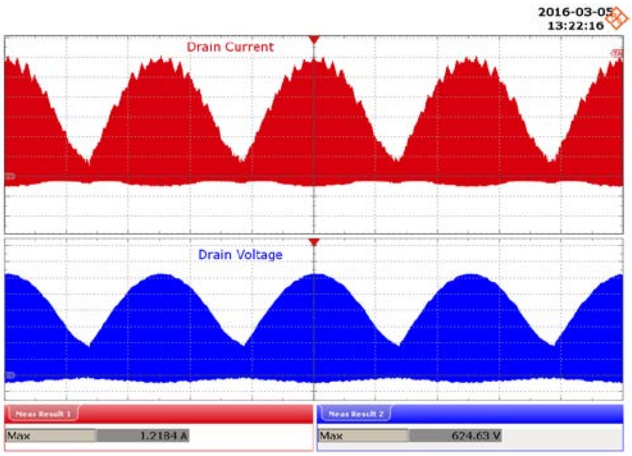

Figure 78 – 265 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

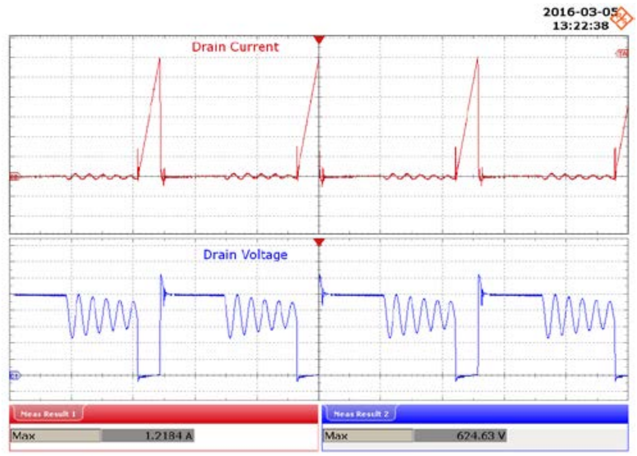

Figure 79 – 265 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

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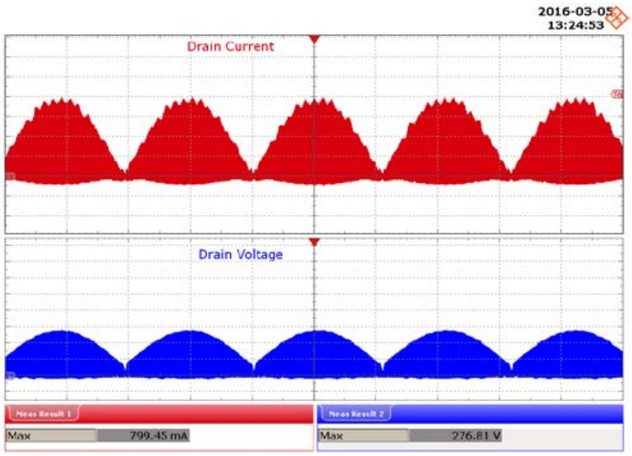

Figure 80 – 90 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

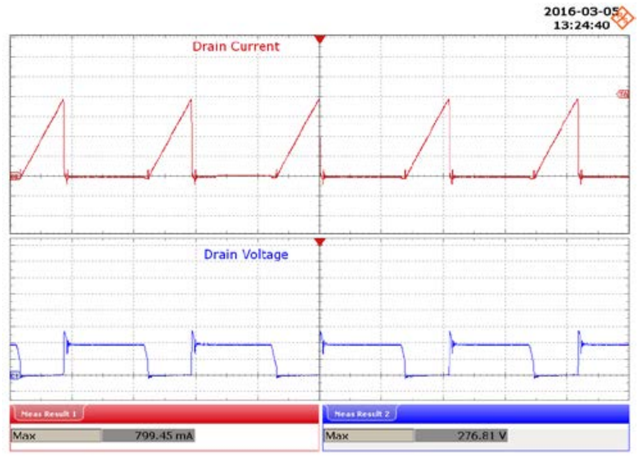

Figure 81 – 90 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

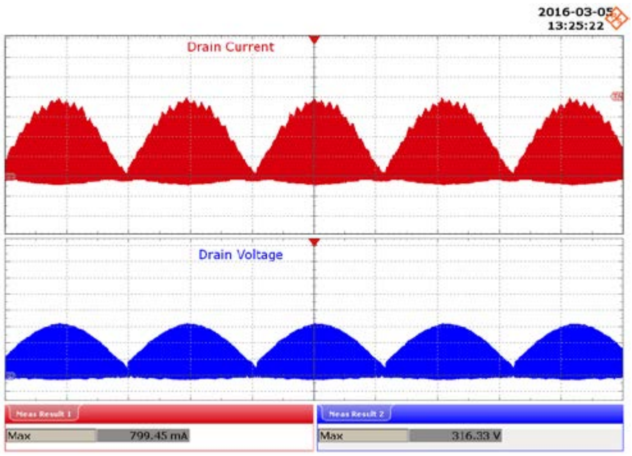

Figure 82 – 115 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

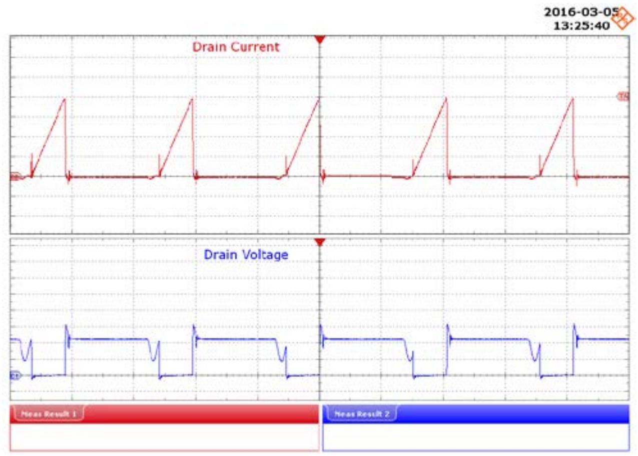

Figure 83 – 115 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

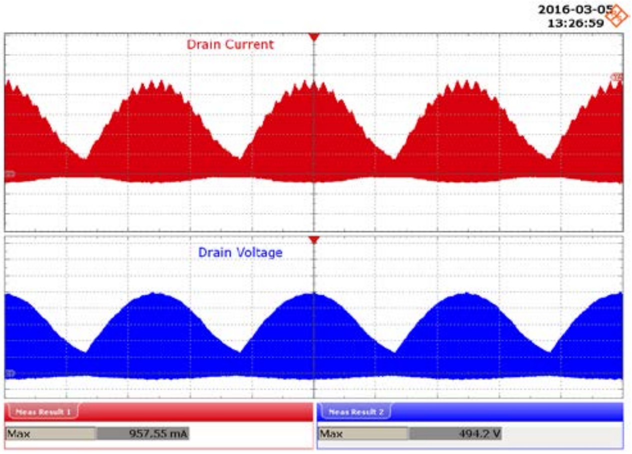

Figure 84 – 230 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 85 – 230 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

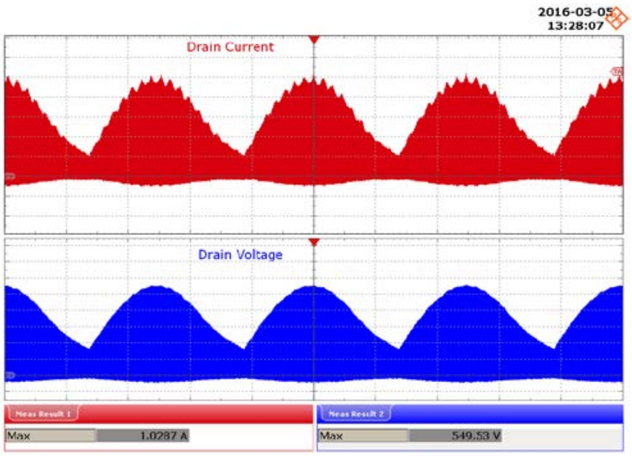

Figure 86 – 265 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 87 – 265 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

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12.5 Drain Voltage and Current Start-up Profile

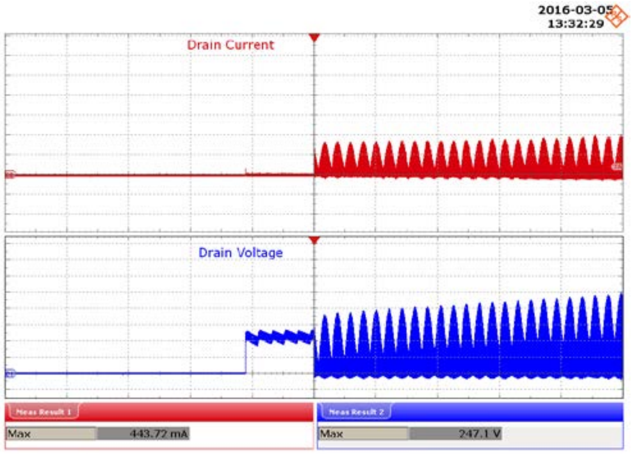

Figure 88 – 90 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 40 ms /div.

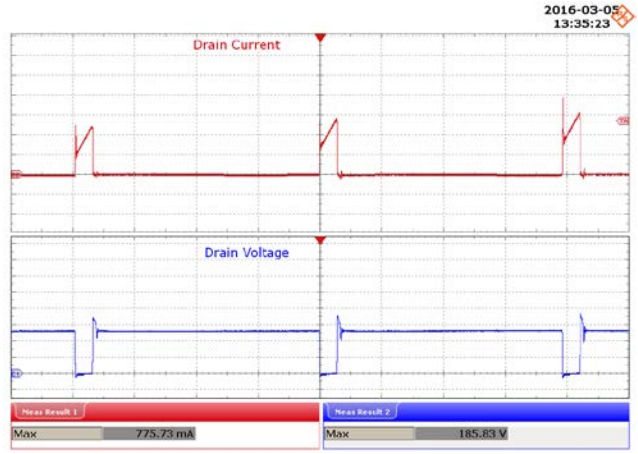

Figure 89 – 90 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs /div.

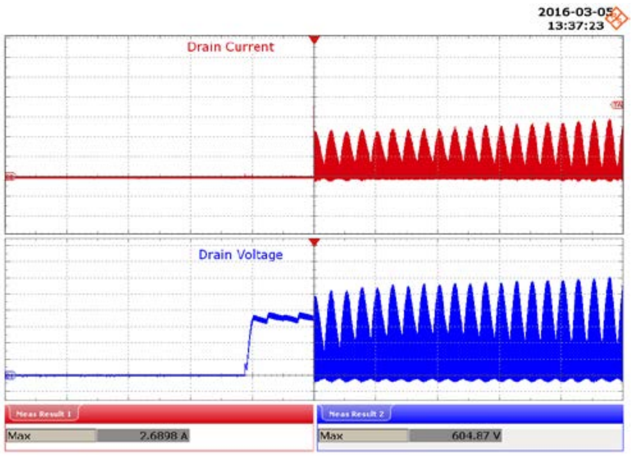

Figure 90 – 265 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 40 ms /div.

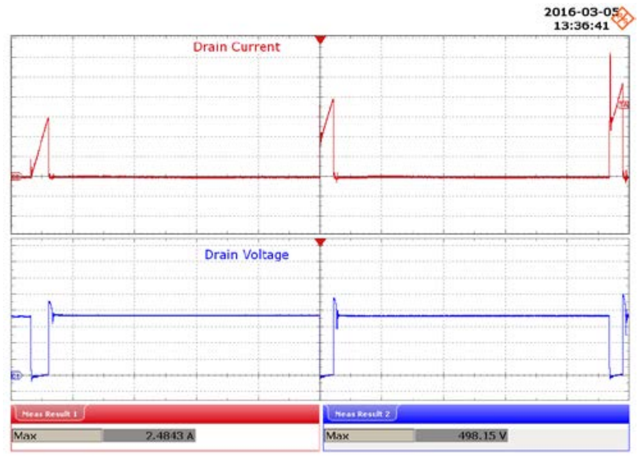

Figure 91 – 265 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs /div.

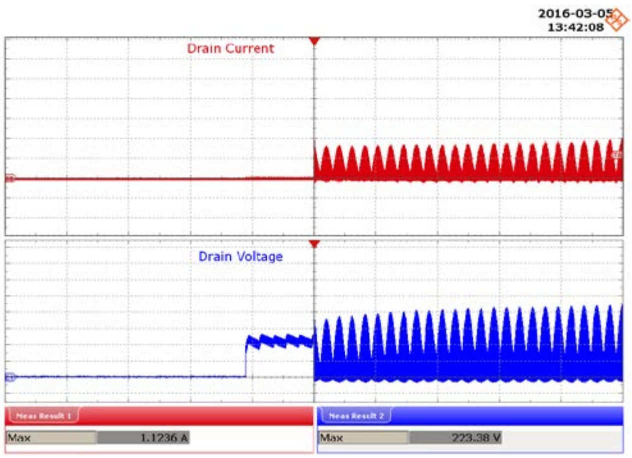

Figure 92 – 90 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 40 ms /div.

Figure 93 – 90 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs /div.

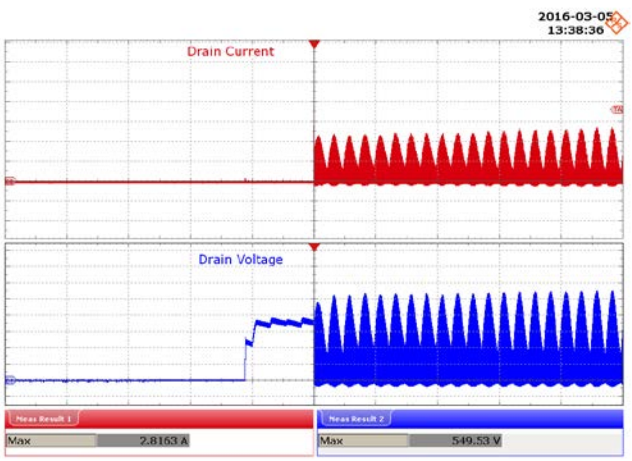

Figure 94 – 265 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 40 ms /div.

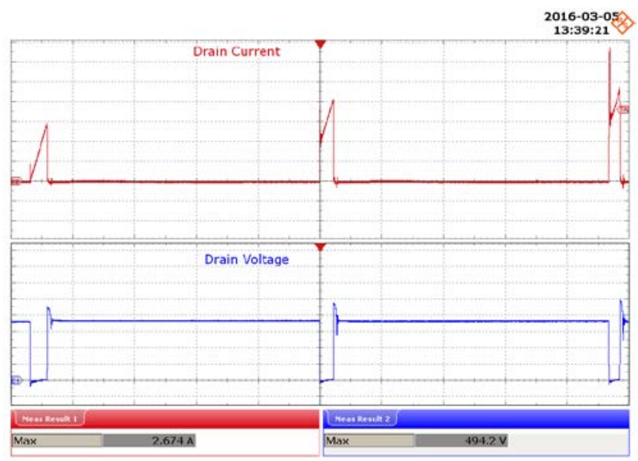

Figure 95 – 265 VAC, 20 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs /div.

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12.6 Drain Voltage and Current during Output Short-Circuit Condition

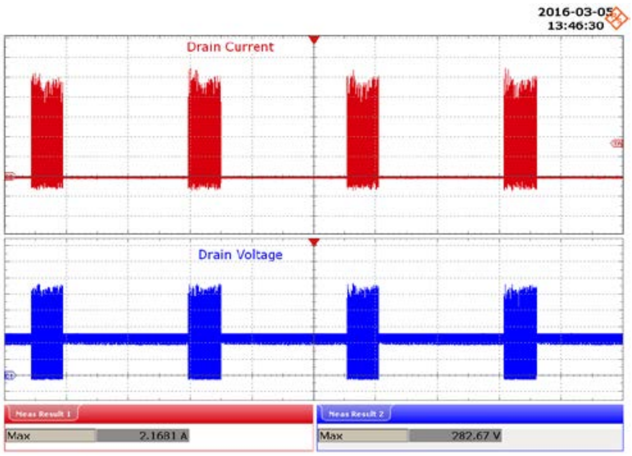

Figure 96 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

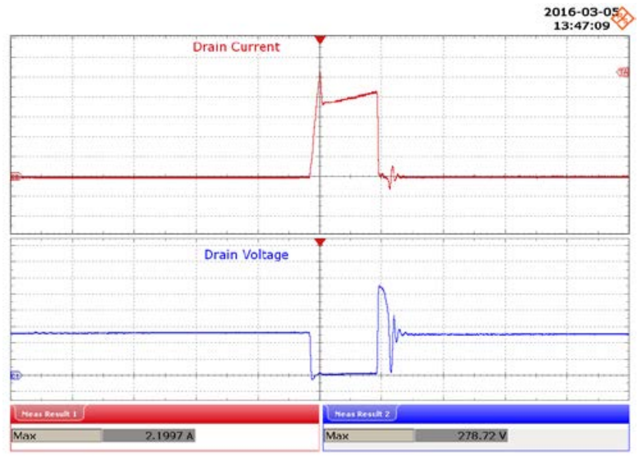

Figure 97 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 μs / div.

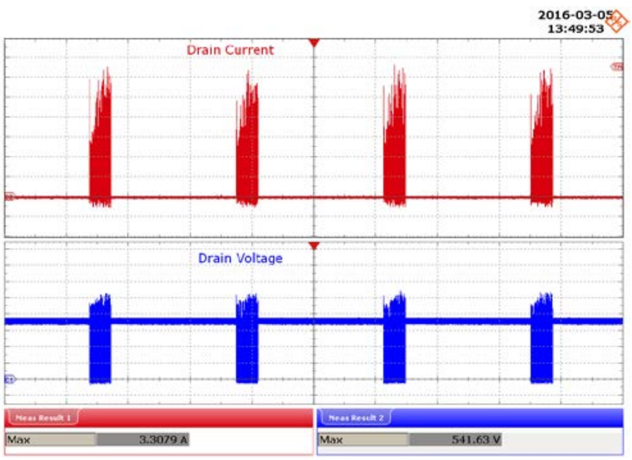

Figure 98 – 265 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

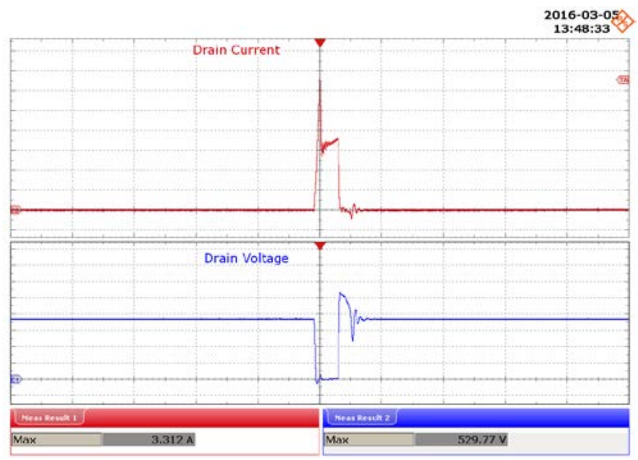

Figure 99 – 265 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs / div.

12.7 Output Diode Voltage and Current in Normal Operation

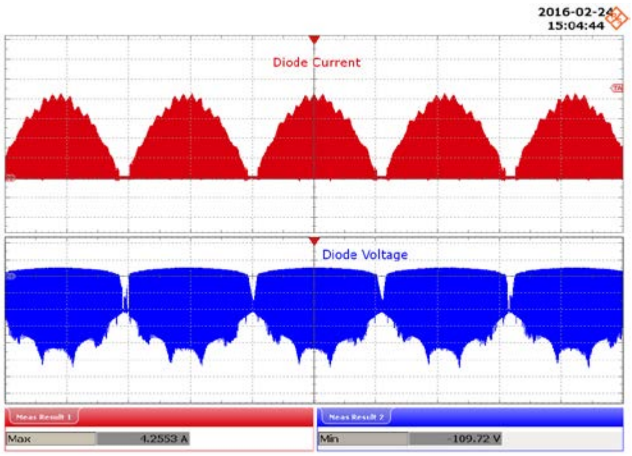

Figure 100 – 90 VAC, 40 V LED Load.
Upper: I_{D3}, 1 A / div.
Lower: V_{D3}, 20 V / div., 4 ms / div.

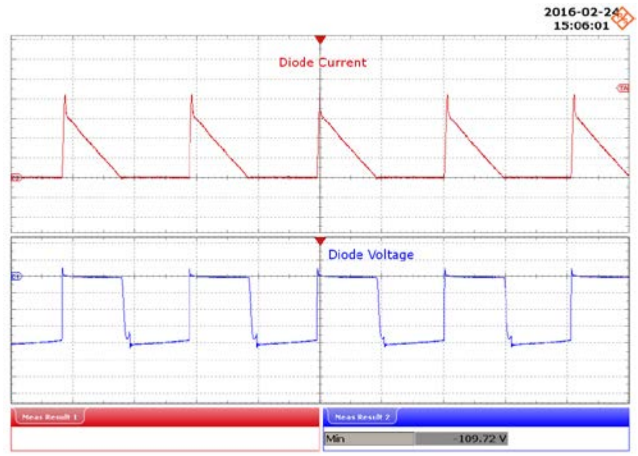

Figure 101 – 90 VAC, 40 V LED Load.
Upper: I_{D3}, 1A / div.
Lower: V_{D3}, 20 V / div., 4 μs / div.

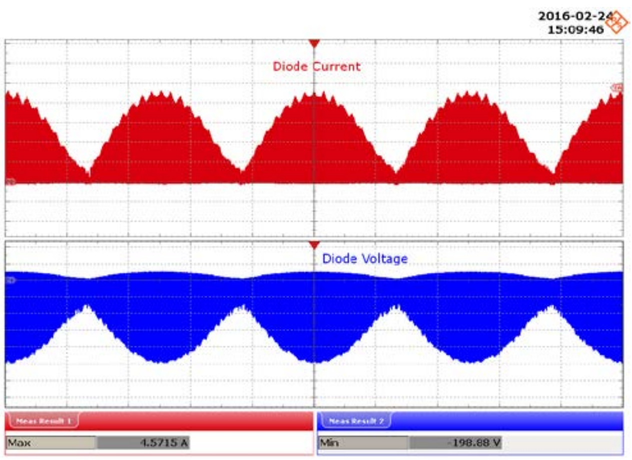

Figure 102 – 265 VAC, 40 V LED Load.
Upper: I_{D3}, 1 A / div.
Lower: V_{D3}, 40 V / div., 4 ms / div.

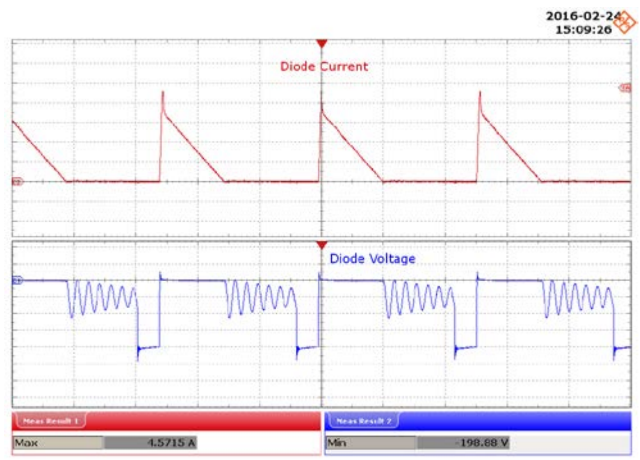

Figure 103 – 265 VAC, 40 V LED Load.
Upper: I_{DRAIN}, 1A / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

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12.8 Output Voltage and Current – Open LED Load

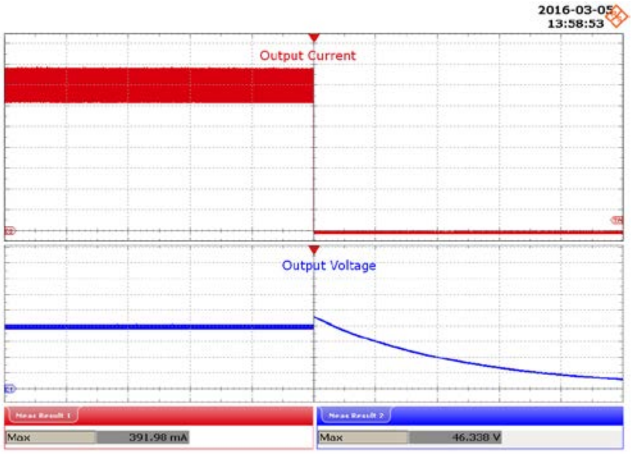

Figure 104 – 90 VAC, 40 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

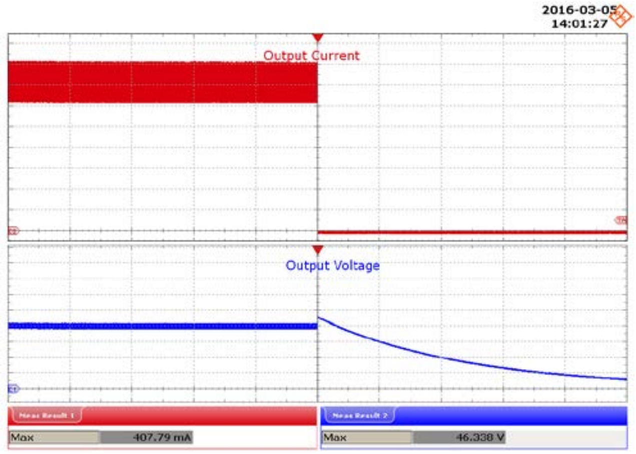

Figure 105 – 265 VAC, 40 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

12.9 Output Voltage and Current – Start-up with Open Load

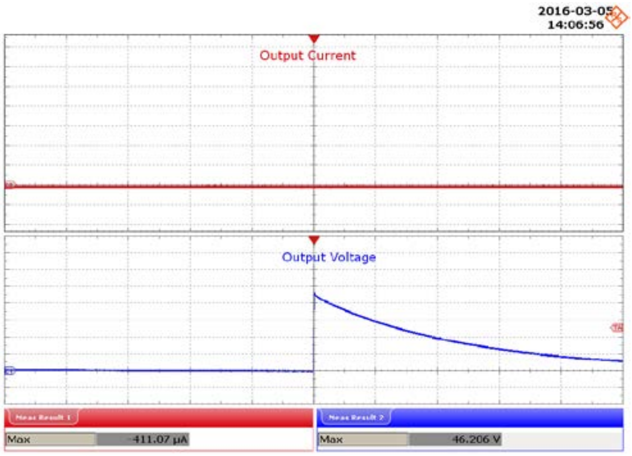

Figure 106 – 90 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

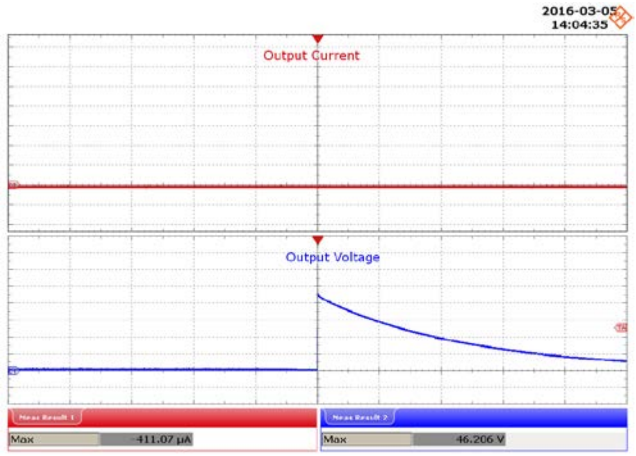

Figure 107 – 265 VAC, Open Load
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

12.10 Output Ripple Current

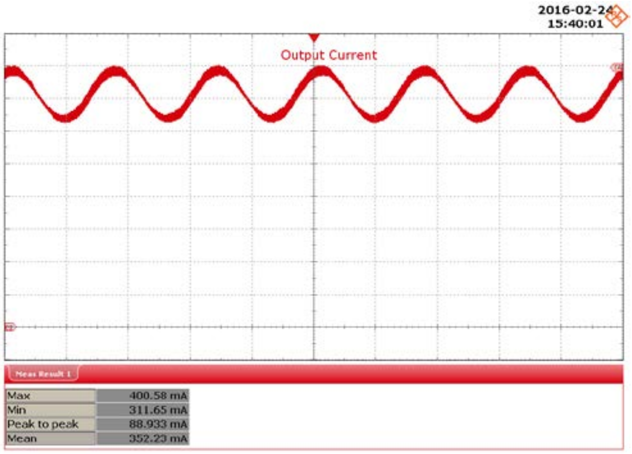

Figure 108 – 90 VAC, 50 Hz, 40 V LED Load.
Upper: I_{OUT}, 50 mA / div., 5 ms / div.

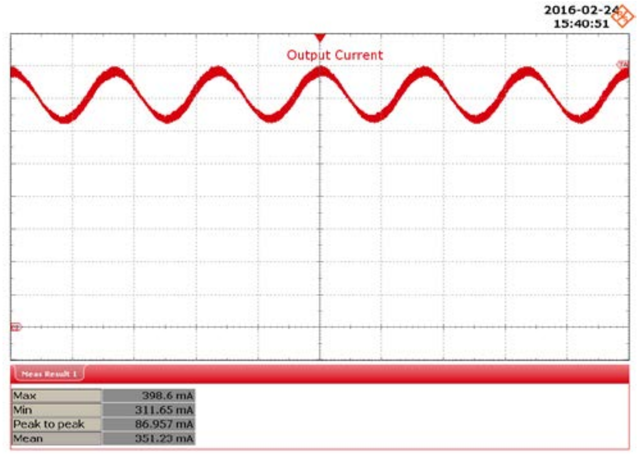

Figure 109 – 115 VAC, 60 Hz, 40 V LED Load.
Upper: I_{OUT}, 50 mA / div., 5 ms / div.

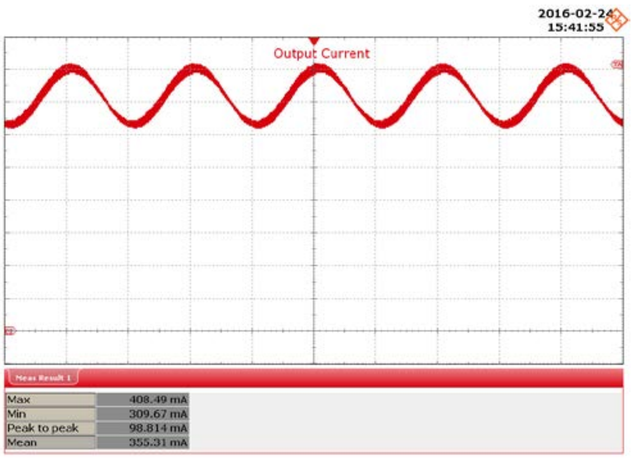

Figure 110 – 230 VAC, 50 Hz, 40 V LED Load.
Upper: I_{OUT}, 50 mA / div., 5 ms / div.

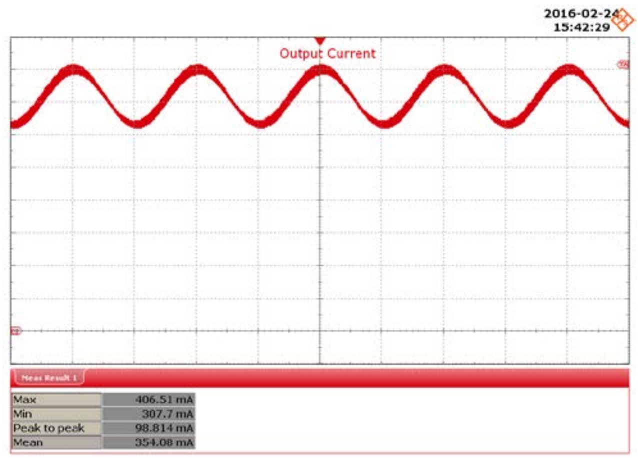

Figure 111 – 265 VAC, 50 Hz, 40 V LED Load.
Upper: I_{OUT}, 50 mA / div., 5 ms / div.

V_{IN}	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN}	Ripple Ratio (I_{RP-P} / I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}+I_{O(MIN)}$)
90 VAC	400.58	311.65	352.23	0.25	12.49
115 VAC	398.6	311.65	351.23	0.25	12.24
230 VAC	408.49	309.67	355.31	0.28	13.76
265 VAC	406.51	307.7	354.08	0.28	13.83

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13 AC Cycling Test

No output current overshoot was observed during on - off cycling.

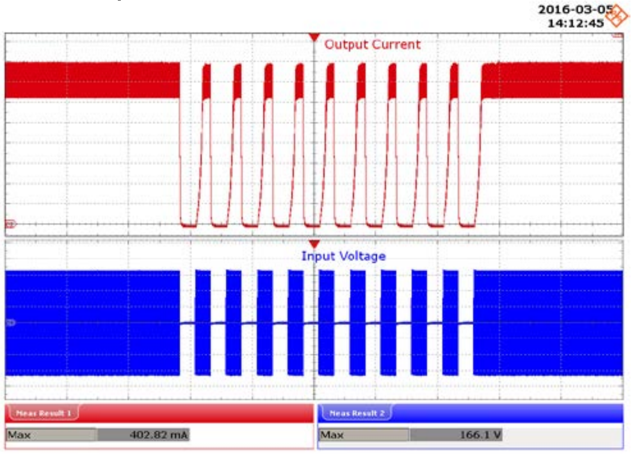

Figure 112 – 115 VAC, 40 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

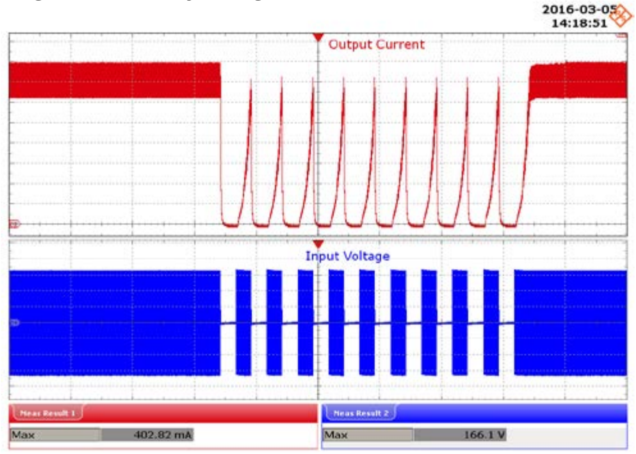

Figure 113 – 115 VAC, 40 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

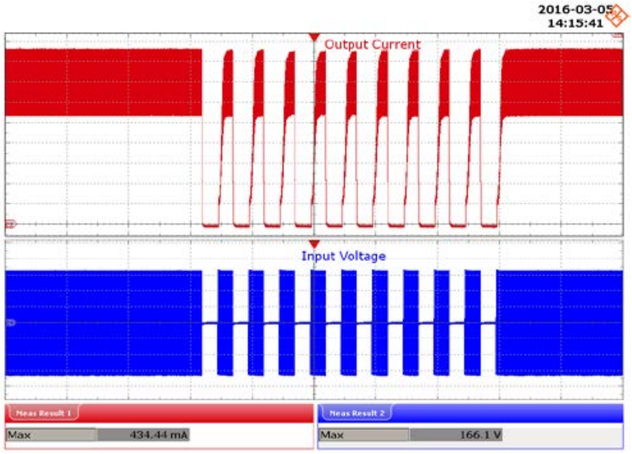

Figure 114 – 115 VAC, 20 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

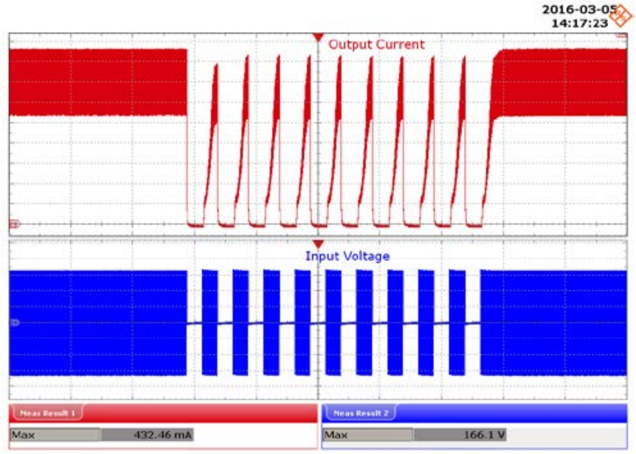

Figure 115 – 115 VAC, 20 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

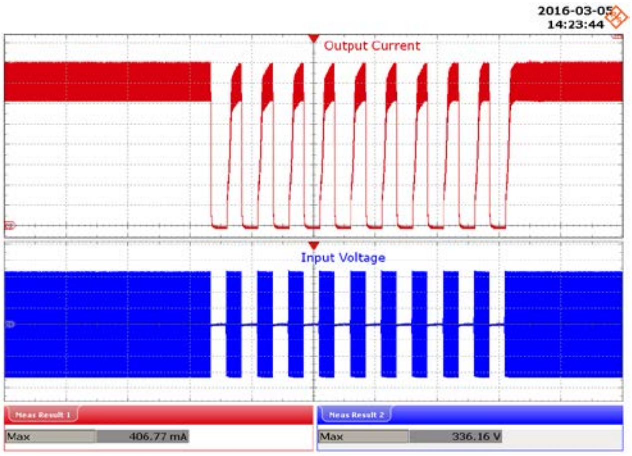

Figure 116 – 230 VAC, 40 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

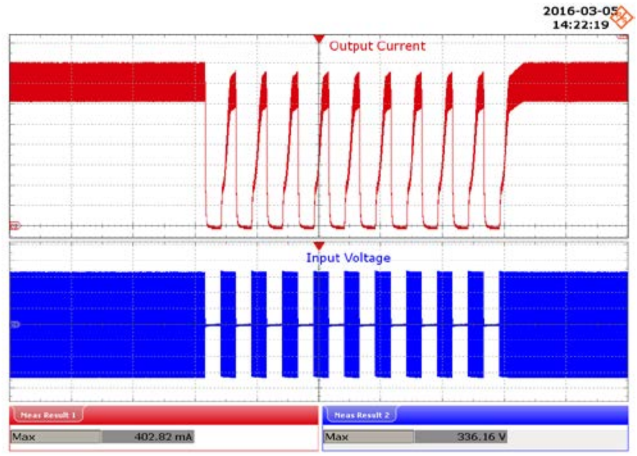

Figure 117 – 230 VAC, 40 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

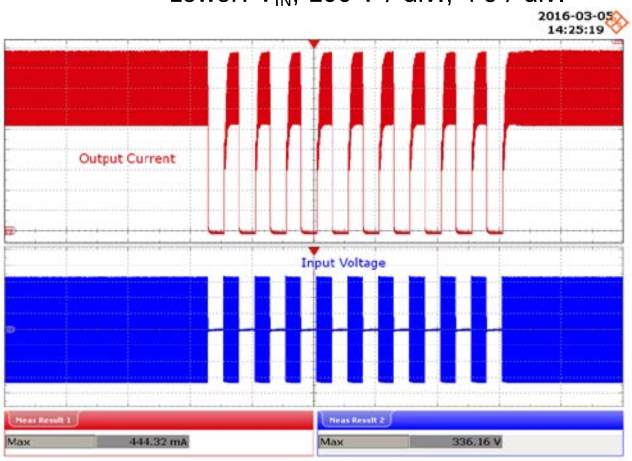

Figure 118 – 230 VAC, 20 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

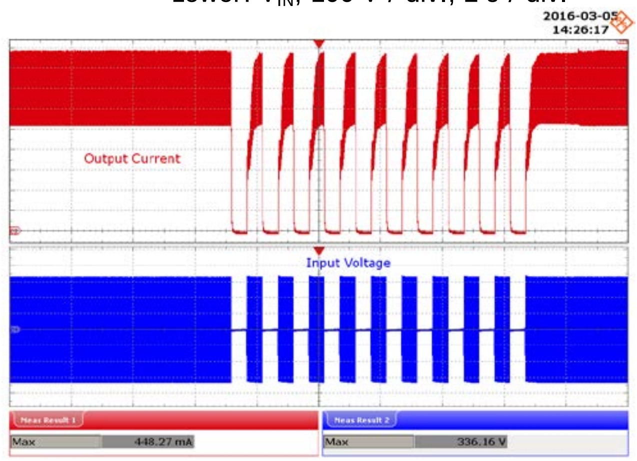

Figure 119 – 230 VAC, 20 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

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14 Conducted EMI

14.1 Test Set-up

14.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. LED load string

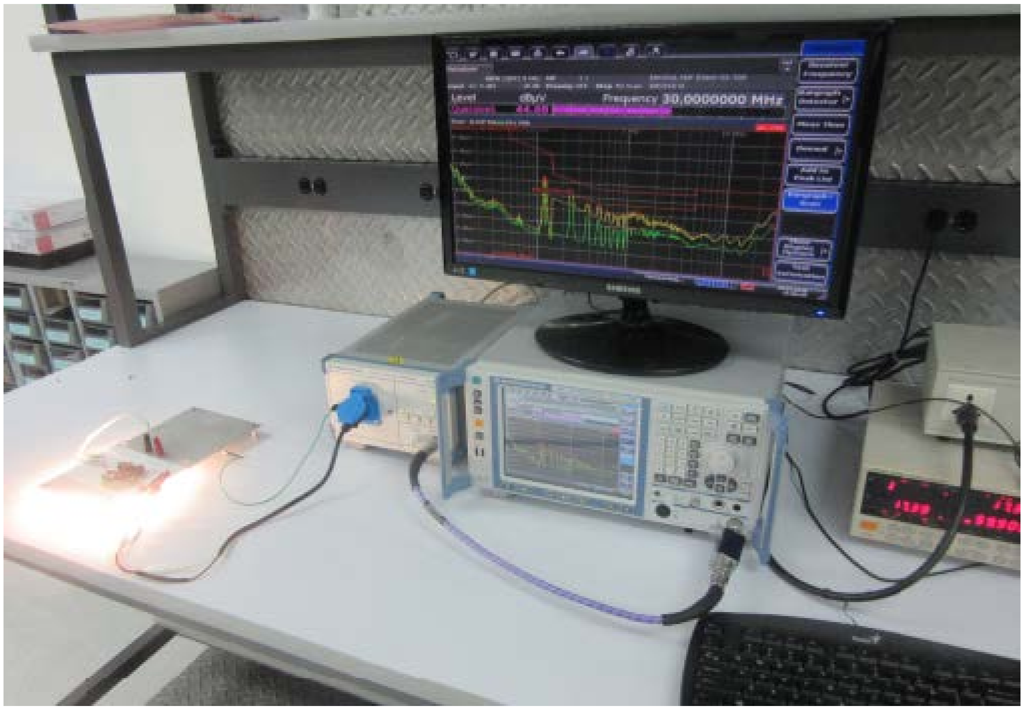

Figure 120 – Conducted EMI Test Set-up.

14.2 EMI Test Result

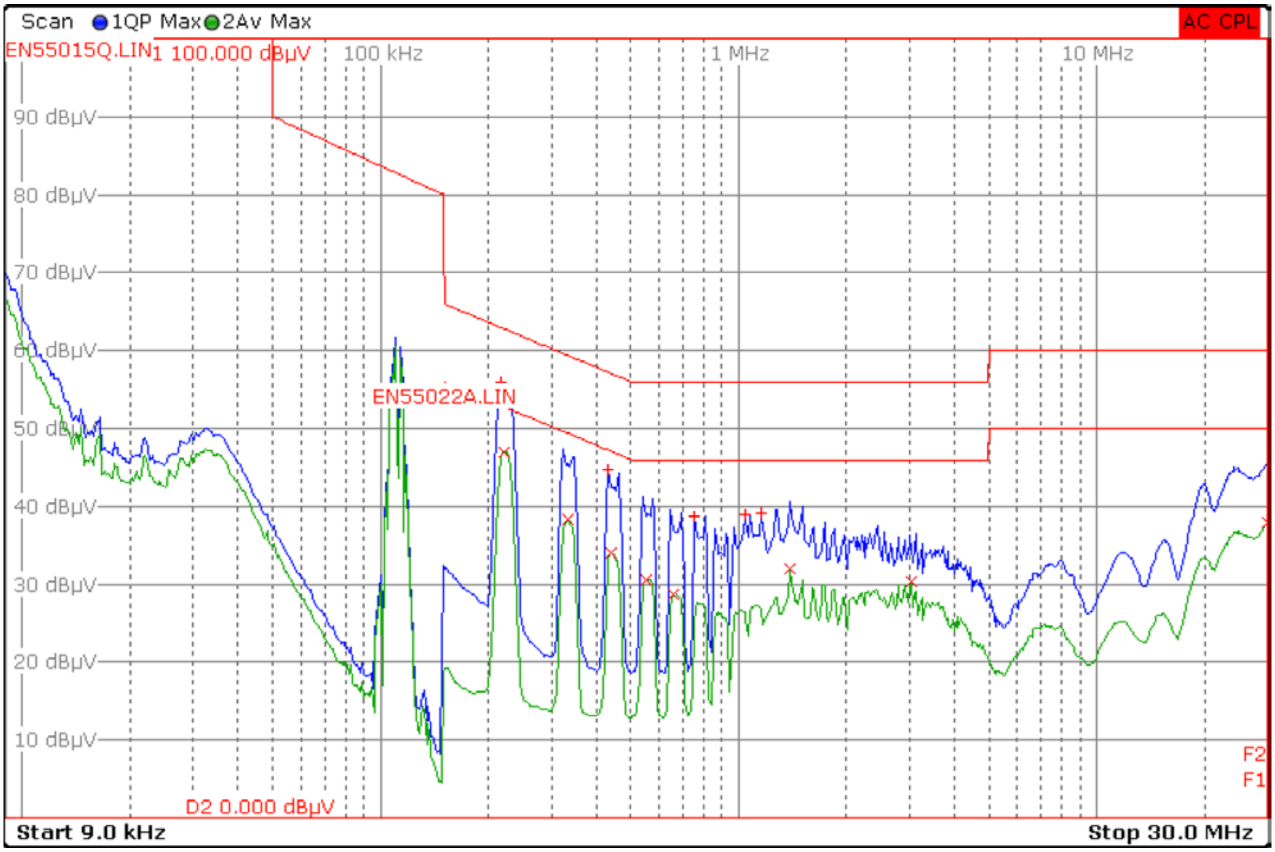

Figure 121 – Conducted EMI QP Scan at 40 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	222.0000 kHz	46.98 N	-5.76 dB
1 Quasi Peak	217.5000 kHz	55.98 N	-6.93 dB
2 Average	334.5000 kHz	38.25 L1	-11.09 dB
2 Average	29.9468 MHz	37.93 L1	-12.07 dB
1 Quasi Peak	433.5000 kHz	44.67 L1	-12.52 dB
2 Average	442.5000 kHz	34.01 L1	-13.00 dB
2 Average	1.3965 MHz	31.98 L1	-14.02 dB
2 Average	550.5000 kHz	30.60 N	-15.40 dB
2 Average	3.0255 MHz	30.27 N	-15.73 dB
1 Quasi Peak	1.1603 MHz	39.14 N	-16.86 dB
1 Quasi Peak	1.0455 MHz	38.98 L1	-17.02 dB
1 Quasi Peak	755.2500 kHz	38.83 L1	-17.17 dB
2 Average	658.5000 kHz	28.70 N	-17.30 dB

Figure 122 – Conducted EMI QP Data at 40 V LED Load, 230 V / 50 Hz.

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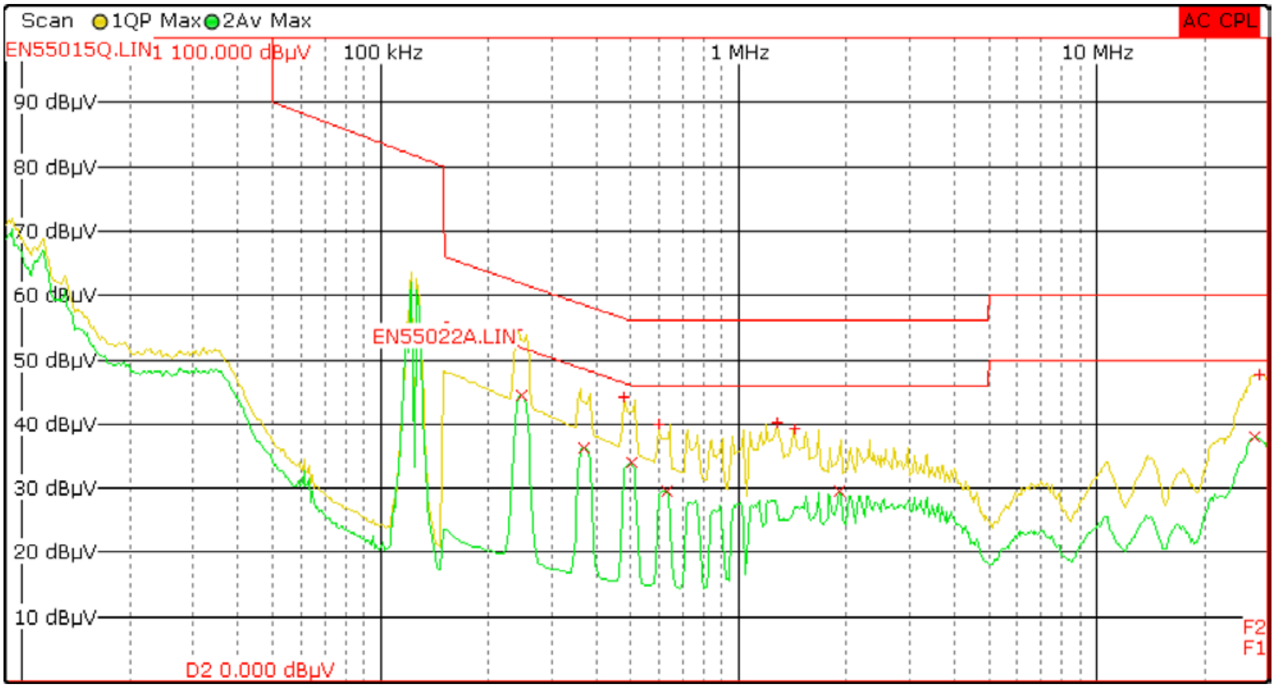

Figure 123 – Conducted EMI QP Scan at 40 V LED Load, 115 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	240.0000 kHz	54.63 N	-7.47 dB
2 Average	249.0000 kHz	44.49 L1	-7.30 dB
2 Average	370.5000 kHz	36.26 L1	-12.23 dB
1 Quasi Peak	480.7500 kHz	44.25 N	-12.08 dB
2 Average	503.2500 kHz	33.94 N	-12.06 dB
1 Quasi Peak	600.0000 kHz	40.05 L1	-15.95 dB
2 Average	631.5000 kHz	29.63 L1	-16.37 dB
1 Quasi Peak	1.2863 MHz	40.19 L1	-15.81 dB
1 Quasi Peak	1.4348 MHz	39.10 L1	-16.90 dB
2 Average	1.9095 MHz	29.48 L1	-16.52 dB
2 Average	27.5438 MHz	37.85 N	-12.15 dB
1 Quasi Peak	28.4460 MHz	47.71 N	-12.29 dB

Figure 124 – Conducted EMI QP Data at 40 V LED Load, 115 V / 50 Hz.

15 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass
+2500	230	L to N	90	Pass
-2500	230	L to N	90	Pass

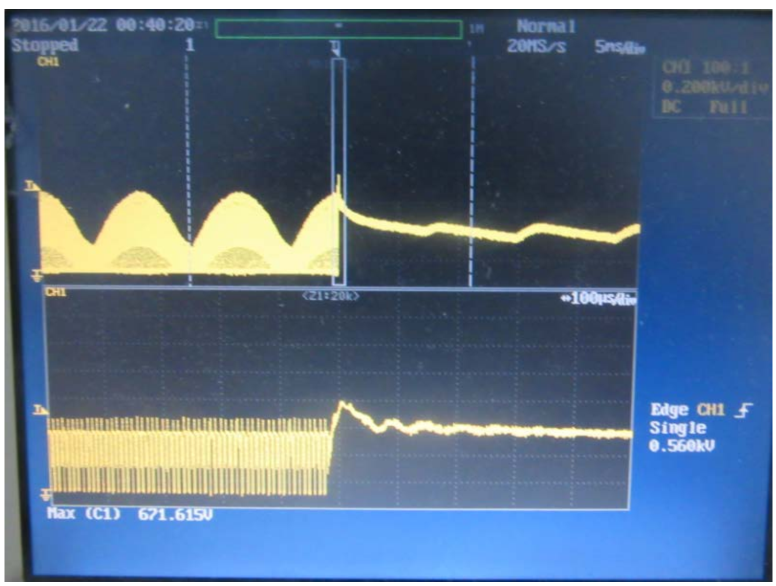

Figure 125 – +1000 kV Differential Surge, 90º Phase Angle
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.
Peak V_{DRAIN}: 671.6 V.

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16 Brown-in/Brown-out Test

No failure of any component was seen during brownout test AC cut-in and cut-off.

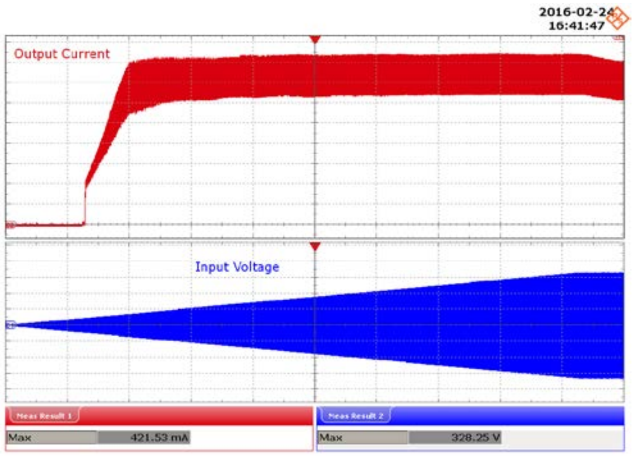

Figure 126 – Brown-in Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 50 mA / div.
Time Scale: 50 s / div.

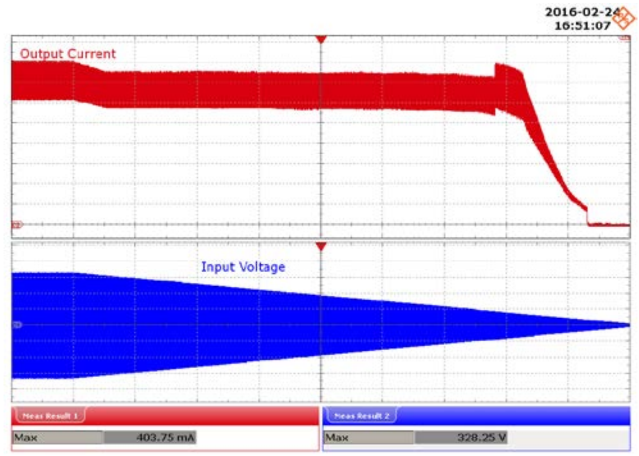

Figure 127 – Brown-out Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 50 mA / div.
Time Scale: 50 s / div.

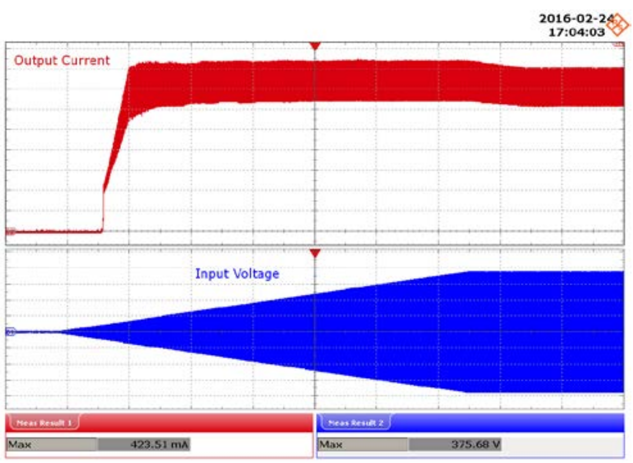

Figure 128 – Brown-in Test at 1 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 50 mA / div.
Time Scale: 40 s / div.

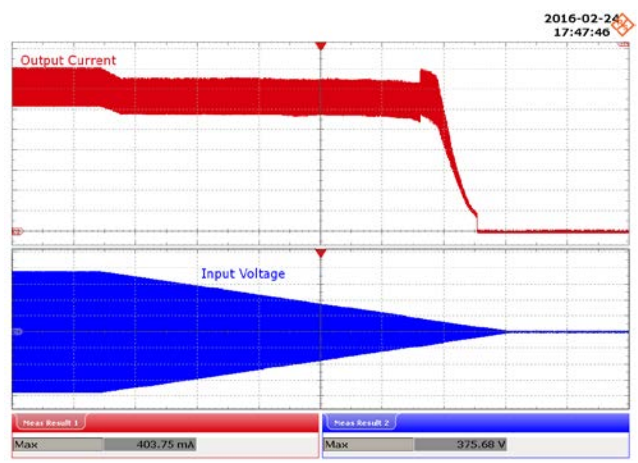

Figure 129 – Brown-out Test at 1 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 50 mA / div.
Time Scale: 40 s / div.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
05-March-16	MGM	1.0	Initial release	Apps & Mktg

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